Water-Quality Assessment of the Trinity River Basin, Texas—Review and Analysis of Available Pesticide Information, 1968–91

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Abstract

In 1991 the Trinity River Basin study unit was among the first 20 study units in which work began under full-scale program implementation of the National Water-Quality Assessment Program. A retrospective assessment was undertaken to review and analyze existing pesticide data and related environmental factors. Population and land-use data indicate human modifications to the landscape and hydrologic system of the study area during the period 1968–91. A variety of crops treated with pesticides were identified, with wheat and cotton accounting for the largest number of acres treated annually (541,250 and 519,870 acres, respectively). Agricultural-use estimates for the later period covered by this report (1988–90) indicate that 105 different pesticides were used and that 24 pesticides accounted for 75 percent of average agricultural use in the study area. Sorghum was treated by the largest number of the 24 most-used pesticides, and cotton was treated by the second largest number of those pesticides. Dimethoate and methyl parathion were the most heavily used of the organophosphate class pesticides. The herbicide 2,4–D was the most heavily used chlorophenoxy pesticide. Carbamate pesticides are used extensively in the study area, with carbaryl, carbofuran, methomyl, and thiodicarb accounting for the majority of the use of this class of pesticide. Miscellaneous pesticides included alachlor, arsenic acid, picloram, and glyphosate, among others. The data indicate that herbicide use generally is proportionally higher in the study area than in the Nation, and that insecticide use in the study area generally is proportionally lower than in the Nation.

Eight different agencies collected the water-quality data used in this report. Samples were collected by all agencies at a combined total of 155 surface-water sites and 121 ground-water sites. The sampled media included water, bed sediment, and tissues of fish and other aquatic wildlife.

Some 273 samples for analysis of the herbicide 2,4–D were collected as part of the city of Arlington's data-collection program. The herbicide was detected in 74 percent of the samples, but none exceeded the Maximum Contamination Level for drinking water.

Dallas Water Utilities collected pesticide samples during a storm in February 1977. Samples were collected at 17 sites with detections of some pesticides in over 50 percent of the samples. Diazinon was detected in 56 percent of samples and 2,4–D was found in 56 percent of samples.

Texas Parks and Wildlife Department collected samples from fish tissue for analyses of organochlorine pesticides from 15 sites in the Dallas-Fort Worth area. Chlordane concentrations in some of the samples exceeded the Food and Drug Administration's action level of 300 micrograms per kilogram.

The Texas Water Commission collected ground-water samples in the study area during 1990 for the major types of pesticides and none were detected. No arsenic was detected in samples from 121 wells in or near the study area. Organochlorine and organophosphate samples were collected beginning in 1974 and ending in 1991. Concentrations of organochlorine pesticides in bed sediment decrease with increasing distance downstream from the Dallas-Fort Worth urban area.

Pesticide samples collected by the U.S. Geological Survey indicated significant rank correlation between number of detects of chlordane and the percent of the contributing watershed classified as urban land use. Dieldrin in bed sediment samples, and lindane, diazinon, and malathion, in water samples, also were significantly correlated with urban land use. Chlordane and dieldrin were significantly correlated with distance downstream from the Dallas-Fort Worth urban area.

Review of all available data showed that pesticides were detected to a substantial degree in various sample media over the time period covered by this report. The authors were able to locate little pesticide-sample data for ground water or for tributary streams because sampling efforts historically have been concentrated on the mainstem Trinity River.

INTRODUCTION

The protection and enhancement of the quality of the Nation's ground and surface waters are among the highest priorities of local, State, and Federal governments. Nationally consistent information on the status and trends in water quality is needed to assess past investment in water-quality management and to provide a base of knowledge for making future decisions. To meet this need, Congress appropriated funds in 1986 for the U.S. Geological Survey to test and refine concepts under a National Water-Quality Assessment (NAWQA) Program. After an initial pilot phase in which methods useful for a full-scale national water-quality assessment program were developed, tested, and refined (Hirsch and others, 1988), the Trinity River Basin was selected to be among the first river basins and aquifer systems (referred to as study units) to be investigated under the full-scale implementation plan. The goals of the NAWQA program (Hirsch and others, 1988) are:

- Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources,
- Define long-term trends (or lack of trends) in water quality, and
- Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends.

The NAWQA program is being executed through 60 (proposed) study units organized on the basis of known hydrologic systems. If the system is dominated by ground water, the study units include large parts of aquifers or aquifer systems. If surface water dominates, the study units are river basins. Study units vary in area from a few thousand to several tens of thousands of square miles. Each study-unit investigation will include assessments of surface- and ground-water quality. Study units are scheduled to undergo cycles of three years of intensive study, followed by 6 years of limited monitoring, at which time the study cycle will be repeated (Leahy and others, 1990).

A major design feature of the NAWQA program is the integration of study-unit investigations as building blocks of national synthesis investigations. This approach will provide results useful at the local and State scale as well as the regional and national scale, in order to construct a coherent picture of water-quality nationally. To this end, this report identifies the most important natural and human factors which influence the spatial and temporal occurrence and distribution of pesticides in the Trinity River Basin.

An on-going effort of the study-unit team is the development of a conceptual model of the water quality of the Trinity River Basin. This model is based on a subdivision of the study area into homogeneous units (regions) representing unique combinations of environmental factors found to be relevant to water quality. The two main assumptions of this regionalization are (1) that the water quality of a stream or aquifer at a particular point is a function of the environmental factors of the region upstream from that point, and (2) by establishing cause and effect relations between the water quality measured at a point on the stream or in the aquifer and the environmental factors in the region upstream from that point, inferences can be made about water quality in unsampled regions having the same or similar mix of environmental factors. The regionalization strategy can be used to guide the design of an optimal sampling network by concentrating sampling resources at locations in the study area where the samples will represent the unique mix of environmental factors. This report contains a brief description of those environmental factors thought to be relevant to pesticide occurrence and distribution within the study area. Relations between study area regions and pesticide detections are described. A more complete description of the study-unit regionalization is contained in Ulery and others (1993). The planning phase of the first cycle for the Trinity River Basin study unit (fig. 1) began in 1991. To meet one of the objectives of the first cycle (3 years of intensive study) of the Trinity River Basin study unit NAWQA, the U.S. Geological Survey in 1991 began an appraisal of the available pesticide data for the study area.

Purpose and Scope

Presented in this report are the results of an investigation of existing pesticide data and relevant environmental factors for the Trinity River Basin study area. Available pesticide data were compiled, screened, reviewed, and analyzed. The data were collected by numerous agencies for differing purposes and within various areas in the study area. Compiled in this report are all available pesticide data, ancillary data relevant to pesticides, and frequency, methods, and collection purposes for the samples. This compilation includes information on investigations conducted, agencies involved, sampling periods, pesticides analyzed, streams or aquifers sampled, and other relevant information. A summary of the sources, types, and periods of record for pesticide data collected in the study area is included. Data presented in this report will (1) improve our understanding of the use, occurrence (in water, bed sediment, and tissues), and distribution of pesticides throughout the study area; (2) contribute local findings to the NAWQA's National Synthesis teams; and (3) aid in the design and refinement of the study-unit pesticide sampling network.

Thematic maps showing the spatial distribution of crops grown in the basin, maps depicting the amounts and locations of pesticide applications, and maps showing where various agencies have sampled for pesticides are included. Summary statistics, graphical summaries, and the results of statistical analysis are presented. The scope of this work includes the review and analysis of available surface- and ground-water pesticide data collected during 1968–91 in the Trinity River Basin and contiguous areas.

Previous Investigations

One of the earliest pesticide investigations within the Trinity River Basin was conducted during 1976–77 by the city of Dallas, Texas (Dallas Water Utilities, 1977). The study was a stormwater runoff investigation in which samples were collected during two storm events. The objective of this study was to identify nonpoint sources of pesticides and other constituents within the Dallas urban area, and it was limited principally to the West and Elm Forks of the Trinity River and the mainstem for a total contributing area of 725 mi^2.

Qasim and others (1980) conducted an investigation during 1976–77 to determine the quality of water and bed sediment in the Trinity River, and the mobility of various contaminants during mixing of bed sediment with river water to simulate dredging operations. The study included sites mainly along the mainstem Trinity River from just upstream of the Dallas-Fort Worth urban area to Livingston Reservoir.

The United States Fish and Wildlife Service conducted a study of contaminant impacts on Trinity River fish and wildlife in 1985 (Irwin, 1988). Samples were collected from the mainstem Trinity River along a 250 mi segment, and from the East and Elm Forks of the Trinity River.

During 1987–88, a water quality and ecological survey was conducted for the Dallas Water Utilities by the University of North Texas and the University of Texas at Dallas (Dickson and others, 1989). Samples were collected upstream and downstream of the Dallas-Fort Worth area.

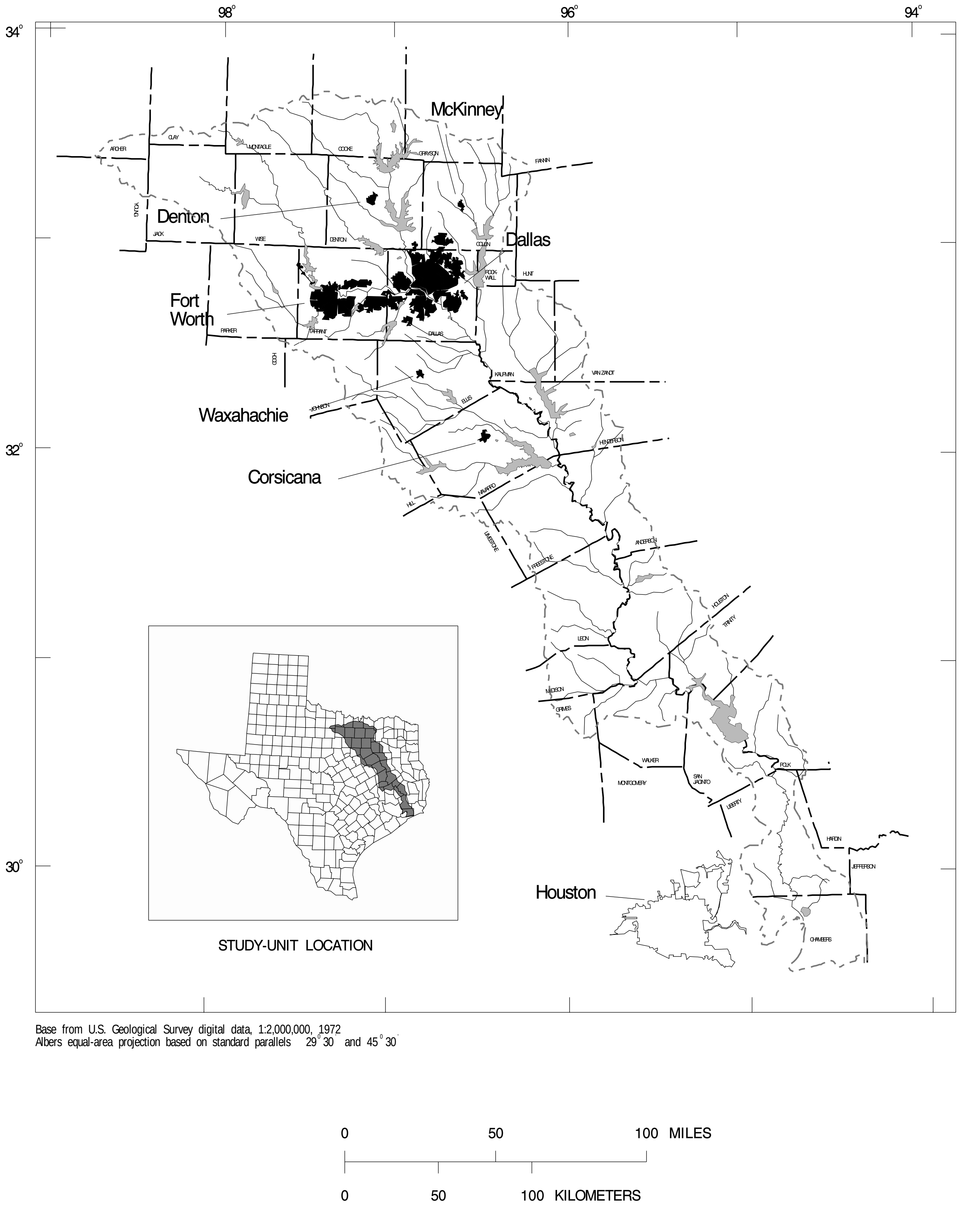

Figure 1. Location and extent of Trinity River Basin study unit.

Acknowledgments

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STUDY-AREA DESCRIPTION

Presented in the following sections is general information about the study unit, hydrology, environmental factors, data concerning the use and occurrence of pesticides, and crop management information.

Location, Extent, and Physiography

The Trinity River Basin NAWQA study area is located (fig. 1) in the south-central United States, in east-central Texas, and extends on a southeast diagonal from immediately south of the Oklahoma-Texas State boundary to the Trinity Bay at the Gulf of Mexico, a distance of 360 mi. The study area boundary is defined as the surface-water drainage divide of the Trinity River, except in the area near the coast where it is comprised of sections of the Chambers County boundary, and part of the western boundary of Liberty County. The study area includes 18,570 mi^2 or seven percent of the area of the State of Texas (267,300 mi^2), with 38 Texas counties at least partially within the study area.

The Trinity River Basin study area is classified as a modified sedimentary landform, which reflects its depositional geologic history, consisting of limestone, chalk, and marl deposits ranging in age from Pennsylvanian to Quaternary (Hill, 1901). The study area is dissected by alternate bands of rolling, treeless prairies, smooth to slightly rolling prairies, rolling timbered hills, and a relatively flat coastal plain. It slopes gradually from 1,200 ft above sea level at the headwaters in the northwest, to about 600 ft at midbasin and to sea level in the southeastern part. The upper areas of Trinity River Basin are covered with a thin mantle of soil, but this mantle increases in thickness and is more extensive moving downstream to the coastal plain and the Gulf of Mexico. The term “Integrated Land Resource Unit” (ILRU) is used in this report to describe unique regions of the study area (Ulery and others, 1993). These 10 ILRUs serve as the basis of the conceptual model of the basin (fig. 2).

Climate

The climate of the study area is temperate. It can be described as modified marine, humid subtropical, with warm summers and a predominant onshore flow of tropical maritime air from the Gulf of Mexico (Carr, 1967). This onshore flow is modified by an east to west decrease in moisture, and by intermittent seasonal intrusions of continental air. The variation in climate within the study area is attributed to the changes in land elevation over the basin from west to east, and the proximity to the Gulf of Mexico and the southern Great Plains. Most of the study area endures a winter surplus and a summer deficiency of precipitation. The most northwestern section of the study area experiences little or no water surplus in any season, and the southeastern tip of the basin experiences no water deficit in any season. Rangeland and dry cropland are prevalent in the drier northwest section of the study area, and rice farms and cattle ranches in the more humid southeast.

Thunderstorms commonly occur during spring and summer and long-duration low-intensity storms triggered by continental polar fronts occur during the fall and winter (Carr, 1967). Average annual precipitation (Larkin and Bomar, 1983) ranges from less than 32 in. in the North Central Prairie to greater than 52 in. in the Coastal Prairie (fig. 3*A*). Average annual temperature (Larkin and Bomar, 1983) is fairly uniform, ranging from about

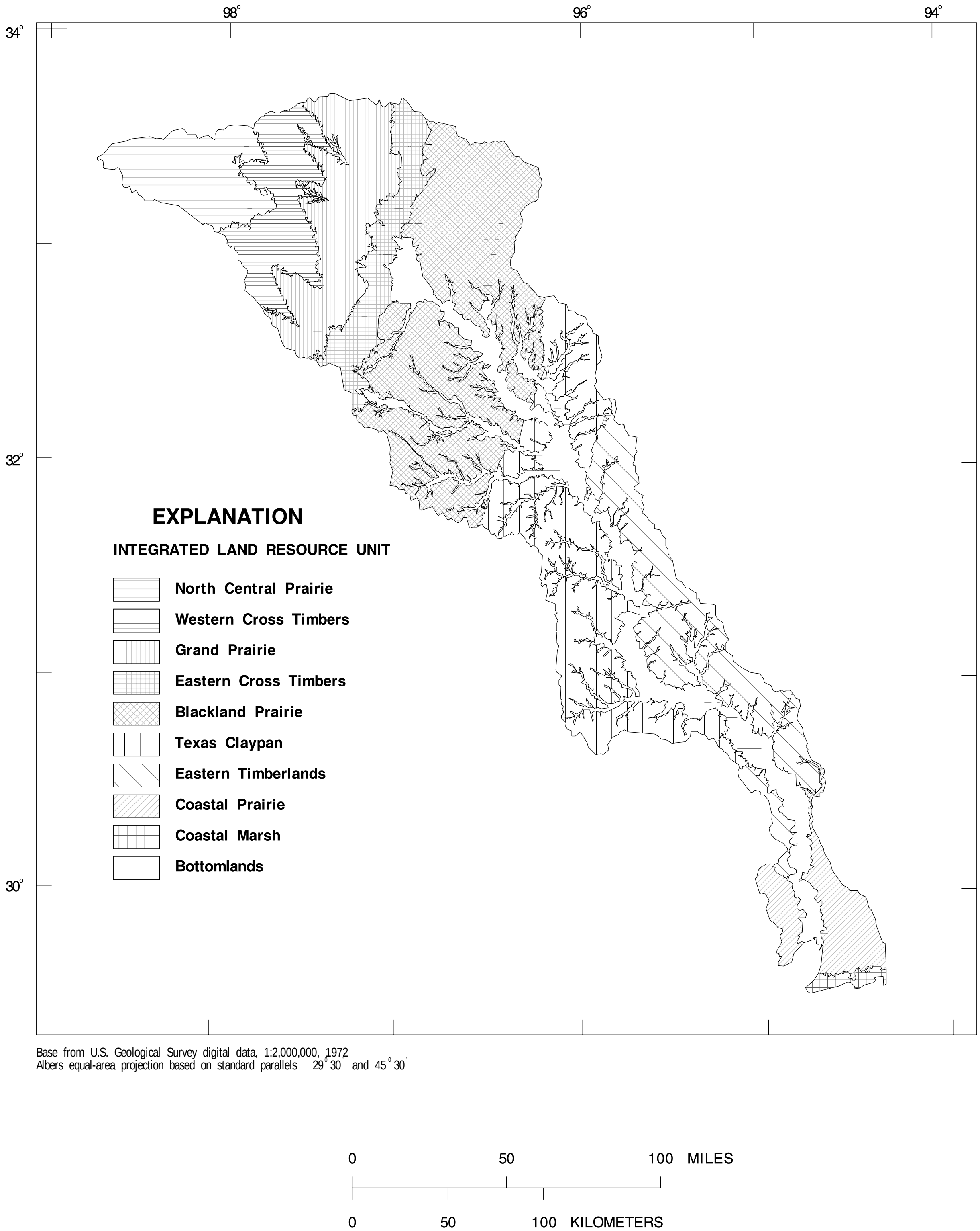
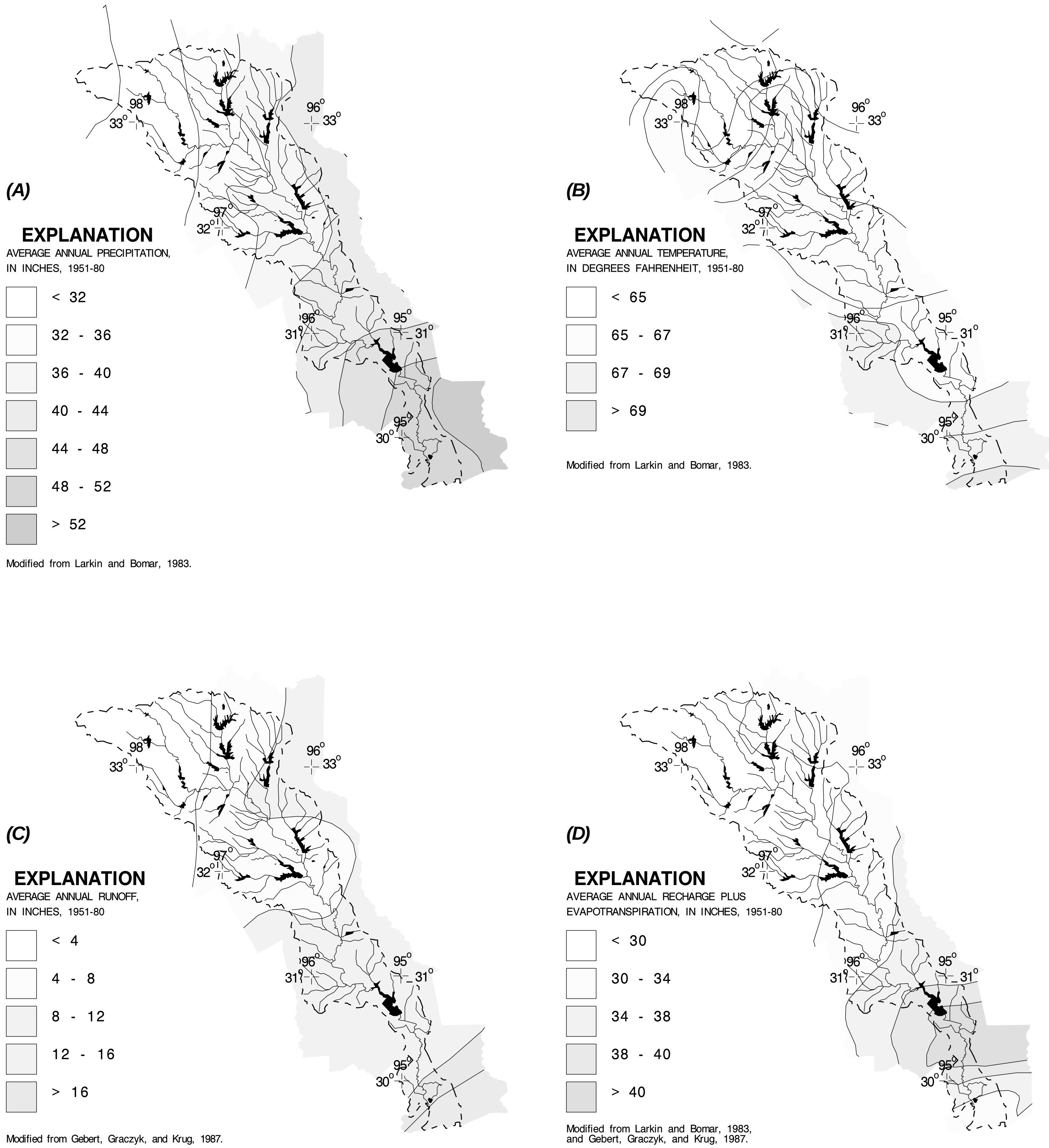


Figure 2. Integrated Land Resource Units (ILRU).



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers equal-area projection based on standard parallels 29°30' and 45°30'

0 50 100 MILES

0 50 100 KILOMETERS

Figure 3. Average annual (*A*) precipitation, (*B*) temperature, (*C*) runoff, and (*D*) recharge plus evapotranspiration.

69 °F in the Coastal Marsh area of the study area to about 65 °F in the North Central Prairie (fig. 3*B*). Average annual runoff (Gebert and others, 1987) ranges from less than 4 in. in the North Central Prairie to greater than 16 in. in the Coastal Prairie ILRU (fig. 3*C*). Average runoff increases from west to east coinciding with the increase in average annual precipitation from west to east. Evapotranspiration plus ground-water recharge (Larkin and Bomar, 1983; Gebert and others, 1987) over the study area averages less than 30 in. in the northwest to greater than 40 in. in the southeast (fig. 3*D*).

Geohydrologic Setting

The geology and geohydrology of the Trinity River Basin reflects the various depositional phases which have occurred through geologic time. In general, rocks of Cretaceous, Tertiary, and Quaternary age are the major water-bearing strata. These rocks consist of an alternating sequence of marine and continental strata created as a result of repeated transgression and regression of the sea. The rocks of Cretaceous age dip east-southeast at an increasing angle. Rocks of Tertiary and Quaternary age dip southeast at increasing angle.

There are three major aquifers in the Trinity River Basin: Trinity Group of Cretaceous age, Carrizo-Wilcox of Tertiary age, and Gulf Coast of Tertiary and Quaternary age. There also are three minor aquifers in the study area: the Woodbine (Cretaceous age), Queen City (Tertiary age), and Sparta (Tertiary age). A more comprehensive description of the geology and geohydrology of the study area may be found in Ulery and others (1993).

The Trinity Group aquifer includes the Travis Peak, Glen Rose, and Paluxy Formations. Rocks of the Trinity Group aquifer outcrop in the northwestern part of the Trinity River Basin (fig. 4). Recharge to the aquifer is primarily from rain falling on the outcrop area. The water-bearing zones consist mostly of fine-grained quartz sand in lenses or layers which, individually, are as much as 50 ft thick. Clay and shale lenses interfinger with the sand lenses, and gradations from sand to clay occur laterally and vertically. Land-use information for the period 1973–84 shows a significant proportion of the aquifer outcrop area used for agriculture, with 48 percent of the outcrop in cropland or pasture.

The Carrizo-Wilcox aquifer includes the Wilcox Group and the overlying Carrizo Formation of the Claiborne Group. The Wilcox Group consists of interbedded sand, sandstone, shale, sandy shale, and lignite. The Carrizo Formation is a white to gray, well-sorted, sand or poorly cemented sandstone. Primarily, the aquifer recharges in the outcrop and discharges to wells, overlying beds, and the underlying saline zone. During the period 1973–84, there was significant agricultural use of the aquifer outcrop area with 58 percent of the outcrop in cropland or pasture.

The Gulf Coast aquifer is composed of seven stratigraphic units which outcrop over much of the lower Trinity River Basin. These include the Catahoula Sandstone, Oakville Sandstone, Lagarto Clay, Goliad Sand, Willis Sand, Lissie Formation, and Beaumont Formation as well as overlying surficial deposits of alluvium. The aquifer consists of alternating beds of clay, silt, sand, and gravel which are hydraulically connected and form a large, leaky artesian-aquifer system. The principle water-bearing units are the Goliad Sand, Willis Sand, and Lissie Formation. Much of the aquifer’s recharge originates in the outcrops of the individual formations. Five percent of the aquifer outcrop area was used for agriculture.

The Woodbine aquifer is composed of lenticular, crossbedded, loose to slightly consolidated, fine-grained sand and sandstone that is interbedded with clay. Sand beds make up about 50 percent of the aquifer and are more common near the base of the aquifer. The aquifer is exposed at the surface in a narrow belt from southeastern Cooke County to Johnson County. The Woodbine aquifer dips eastward into the subsurface of northeast Texas where it reaches a maximum thickness of about 700 ft. A major part of the aquifer outcrop area was used for agriculture with 64 percent in cropland or pasture.

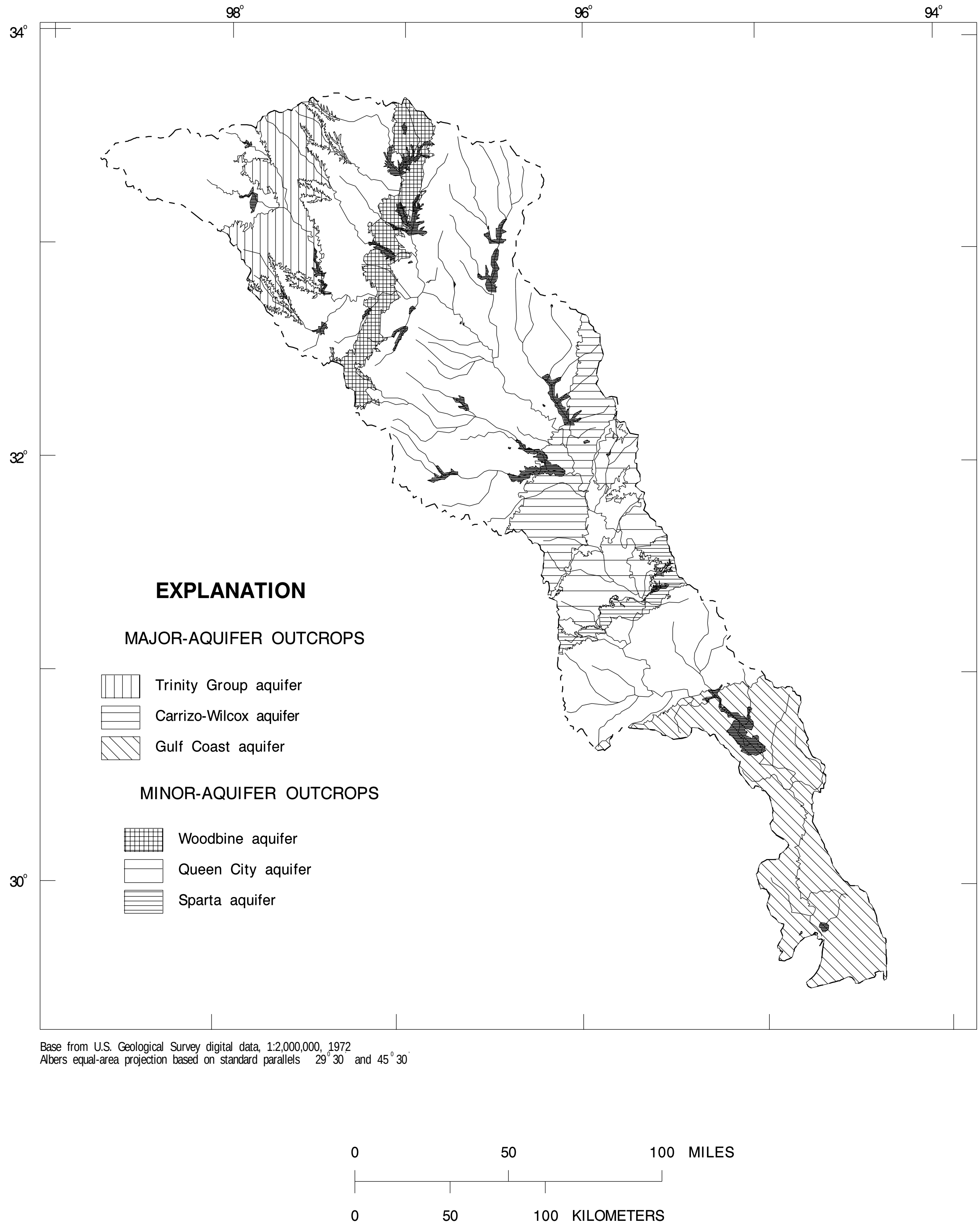


Figure 4. Major and minor aquifer outcrop areas.

The Queen City aquifer consists of crossbedded, medium- to very fine-grained sand. The sand beds are massive to thin and interbedded with lenses of shale and sandy shale. Lignite is present in some locations. Recharge is mostly from the outcrop area, and 44 percent of the area was used for cropland or pasture.

The Sparta aquifer is composed mainly of medium-grained sands and interbedded clays. Sand makes up 60 to 70 percent of the total thickness which ranges from 100 to approximately 300 ft. The Sparta outcrops in southern Leon and northern Houston Counties, and recharge originates primarily in this area. Some 36 percent of the outcrop area was used for cropland or pasture.

Hydrography

The headwaters of the Trinity River are in the North Central Prairie in the northwest and the Eastern and Western Cross Timbers, Grand Prairie, and Blackland Prairie ILRUs in the north and northeast. The western part of the basin is drained by the Clear Fork Trinity River and the West Fork Trinity River, which join in Fort Worth (fig. 5). The north-central part of the basin is drained by the Elm Fork Trinity River. The Elm Fork Trinity River joins the West Fork Trinity River in Dallas to form the Trinity River. The northeast part of the basin is drained by the East Fork Trinity River which joins the Trinity River 20 mi southeast of Dallas.

The central part of the basin is drained by two tributaries, Cedar Creek in the east and Richland Creek in the west. Both tributaries drain parts of the Blackland Prairie and the Eastern Cross Timbers. The southern section of the basin, downstream from the mouth of Richland Creek, narrows to 45 mi. Tributaries in this section of the study area are generally small and drain the Texas Claypan from the east, the Eastern Timberlands from the west, and the Coastal Prairie in the south.

The natural stream network has been extensively modified by man. Numerous reservoirs have been built to retain runoff from all the major tributaries as well as from the mainstem of the Trinity River for water supply. Diversions move water within the basin and to and from adjacent river basins. Medium and large reservoirs are shown on figure 5 (greater-than 10,000 acre-ft capacity). In addition to those 22 reservoirs, there are about 1,000 smaller reservoirs in the basin. Most of these are flood-retarding structures with capacities between 500 and 1,000 acre-ft.

Water Use

Municipal water use is the study area’s major demand. Surface water is the main source of water supply for the study area, and is predicted to remain so in the future (Texas Water Development Board, 1990). Total water withdrawals for 1990 were 3,164,000 acre-ft, and of that amount, an estimated 418,000 acre-ft, or 13 percent, was consumptive. Surface-water withdrawals in 1990 were estimated to be 2,920,000 acre-ft (Dee Lurry, U.S. Geological Survey, written commun., 1992). The rice-producing coastal area of the study area is the only substantial irrigated area, and is supplied by surface water with some supplemental ground water from the Gulf Coast aquifer (Texas Department of Water Resources, 1984). Withdrawals for irrigation totaled 150,000 acre-ft in 1990 with an estimated 68,500 acre-ft of consumptive use. Livestock water use in the Trinity River Basin totaled 23,000 acre-ft in 1990. The current pattern of water use is not expected to change substantially over the next 50 years (Texas Water Development Board, 1990).

Population and Land Use

The Trinity River NAWQA study area contains two of the four most populous counties in the State, Dallas and Tarrant, with their combined 1990 population of about 3 million (A.H. Belo Corp., 1991). These two counties alone account for 19 percent of the State’s total population, as well as 66 percent of the total population of the study area (4.5 million). Over the period 1980 to 1990, Dallas and Tarrant Counties showed the second and third largest numerical increases of the five largest growth counties in the State. Denton County showed the largest percentage increase (91 percent) of all counties in the State during the same period,

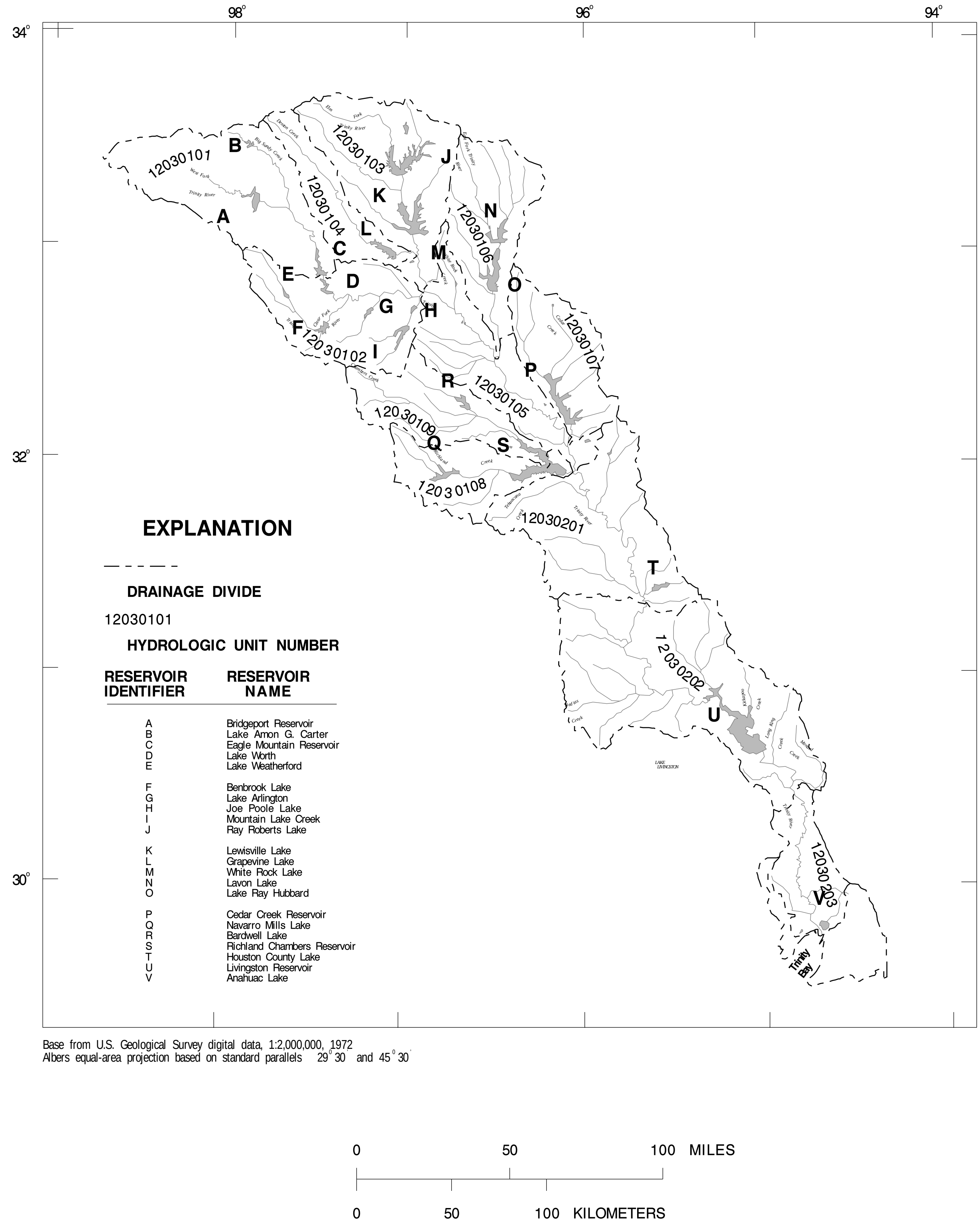


Figure 5. Stream network, major reservoirs, and hydrologic units.

followed by Collin County (86 percent), and Rockwall County (76 percent). Also, during this period, Texas' total population increased by 19 percent, but the population of the study area increased by 26 percent, indicating that the study area continues as one of the major growth areas in the State. Population density of the State overall is 67 persons per square mile, but within the study area population density is 259 persons per square mile. Most people live in or around the cities of Dallas, Fort Worth, Denton, McKinney, Corsicana, Gainesville, Arlington, Irving, and Waxahachie.

The population of the Consolidated Metropolitan Statistical Area covering Dallas-Fort Worth was 3,750,000 people in 1990. The urban and suburban areas include 65 percent of Dallas County, 50 percent of Tarrant County, and limited parts of Denton and Collin Counties. The Consolidated Metropolitan Statistical Area covers approximately 1,500 mi^2 and represents 8 percent of the Trinity River Basin study area. A diverse economic base exists for the Dallas-Fort Worth Metroplex. Major manufacturing industries include automotive, aerospace, electronics, plastics, and oilfield equipment. Large service industries include transportation (the Nation's largest airport), insurance, and finance.

Land use is an important environmental factor, which has a major affect on pesticide distribution and occurrence. An initial land-use and land-cover classification has been applied to the Trinity River Basin study area (Ulery and others, 1993), based on Geographic Information Retrieval and Analysis System (GIRAS) land-use and land-cover data (Anderson and others, 1976). This information is a general approximation of land use and land cover for the period 1973 to 1984, a time period coincident with much of the early pesticide sampling conducted in the study area. Table 1 shows that urban or built-up areas constituted about 5 percent of the study area. Use of pesticides in urban areas is typically on lawns and gardens, in and around buildings, and along roadsides and other rights-of-way in order to control weeds and insects. About 25 percent of the study area was classified as forest land or wetland. Silviculture practices typically involve use of pesticides. Extensive rice-farming activities, with accompanying pesticide use, occurred in wetland areas. Rangeland areas constituted about 10 percent of the study area. Pesticides are used on rangeland—insecticides to control flies and fire ants, and herbicides for weed or other brush control. Table 1 shows that agricultural lands occupied about 57 percent of the study area. The majority of this agricultural land was either cropland or pasture but 1 percent was either orchards or vineyards.

Agricultural Activities

Agricultural activities in the study area are influenced greatly by the prevailing climatic conditions. The average length of the growing season throughout the study area varies from 216 days in the northwest to 260 days in the southeast. This extensive season allows a great variety of crops to be grown during a majority of the calendar year.

Table 1. Land use and land cover in the study unit during 1973–81

[Data from Ulery and others, 1993.]

Land use or land cover	Area (square miles)	Percent of study unit area
Urban or built-up land	1,011	5.4
Agricultural land	10,513	56.6
Rangeland	1,781	9.6
Forest land or wetlands	4,652	25.1
Barren land or water	613	3.3
Total	18,570	100

During the period 1968 to 1991, agricultural lands were being converted to nonagricultural uses, and some inactive agricultural areas were allowed to revert to rangeland. This was generally in keeping with two nationwide trends—the movement of people from rural to urban areas, and the shrinking of the farm population and farm size due to ongoing farm mechanization and increased efficiency. Despite an estimated 15 percent decrease in harvest cropland since 1954, per-acre yields on corn, wheat, and cotton have increased dramatically (Pait and others, 1992). A significant portion of these increases can be attributed to the use of pesticides.

Crop and pesticide-use data for the study area were obtained from the Texas Agricultural Extension Service (Bill Harris, written commun., 1991). The data, originally county based, were recompiled by local agricultural extension agents by hydrologic unit number (fig. 5). This recompilation, based on the hydrologic unit boundaries, is more representative (in terms of water-quality issues) of crop acreage and of the agricultural chemicals applied on that acreage than the county-based data. The hydrologic unit boundary in most instances is coincident with a major drainage divide or watershed boundary. Pesticide samples commonly are collected at the intersection of the stream segment and the drainage area. Therefore, any relation between pesticide applications within the hydrologic unit or drainage area above the sampling site and detections of pesticides in samples collected at that site may be explored in a more credible manner than would be possible with county-based data. Table 2 lists 17 crops treated in the study area, the average areas treated annually, and the number of pesticides applied on each crop. The spatial distribution of the top nine (by average areas treated annually) crops within the basin during 1988–90 is shown on figures 6–8. These nine crops accounted for the majority of acres treated during this period.

Figure 6 shows the average acres of cotton, wheat, and alfalfa or other hay treated within each hydrologic unit for the period 1988–90. The central portion of the study area is intensively farmed, due in part to the presence of the Blackland Prairie, which contains some of the richest farmland in the State, and in part to climatic conditions conducive to the cultivation of these crops. All areas of the study area were involved in some alfalfa or hay production during 1988–90, and these crops probably were consumed by livestock on local rangeland. Figure 7 shows average acres of rice, sorghum, and soybeans treated within each hydrologic unit. In particular, grain sorghum is grown to a large extent in the same Blackland Prairie areas and used as animal feed. Rice and soybeans generally are grown in the more humid southeastern part of the study area. Figure 8 shows average acres planted in corn, peanuts, and pecans. Again, the central portion of the study area is indicated as an intensely farmed area, for corn in particular, with an average of over 100,000 acres planted annually during 1988–90.

A standardized crop classification is an important base for comparison within and between NAWQA study areas, because although the types and application rates for various agricultural chemicals change frequently through time the types of crops grown in a particular area tend to be fairly constant. This crop data can be useful in place of actual field-scale-cropping and pesticide application data (when the data are not uniformly available nationwide) in order to relate historical land-use activities to long-term trends in overall pesticide occurrence and distribution. To create the standardized crop data set for the Nation, NAWQA’s Pesticide National Synthesis project personnel extracted county crop data from the 1987 Census of Agriculture data base (Gianessi and Puffer, 1990). This data set then was combined with cropland and pasture information from the land-use classification. The resultant major crop-group classification, based on percentages of the cropland area within a county planted in selected crops, was used by project personnel during the preparation of this report for comparison and contrast with pesticide occurrence in the study area (Gail Thelin, U.S. Geological Survey, written commun., 1993). The relation of crop groups to pesticide occurrence and distribution within and between the various study units likely will be examined by the NAWQA National Synthesis team. Management practices for these crop groups will be evaluated as to their relation to the water quality in study units across the Nation.

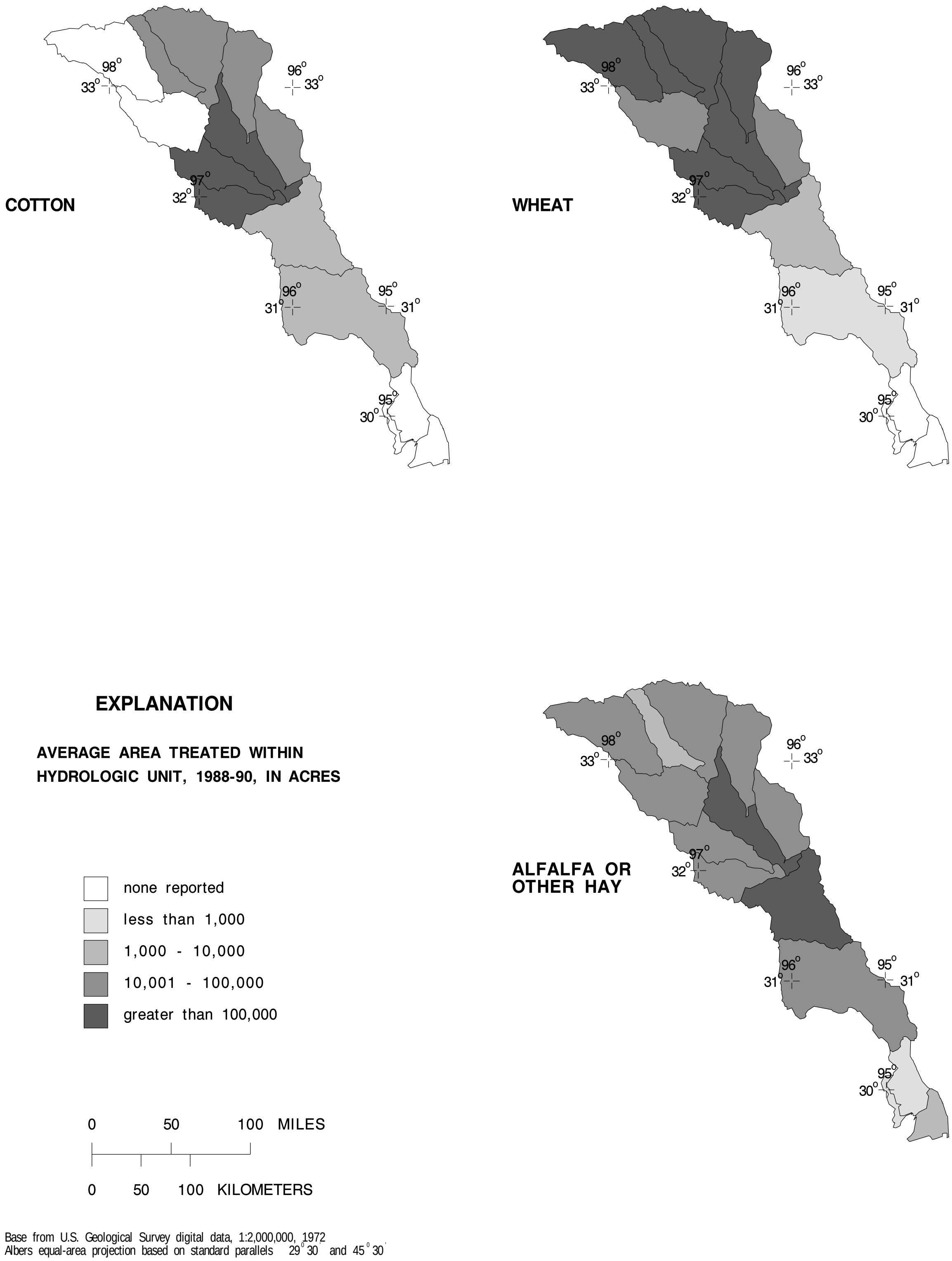


Figure 6. Average areas of cotton, wheat, and alfalfa or other hay treated during 1988–90.

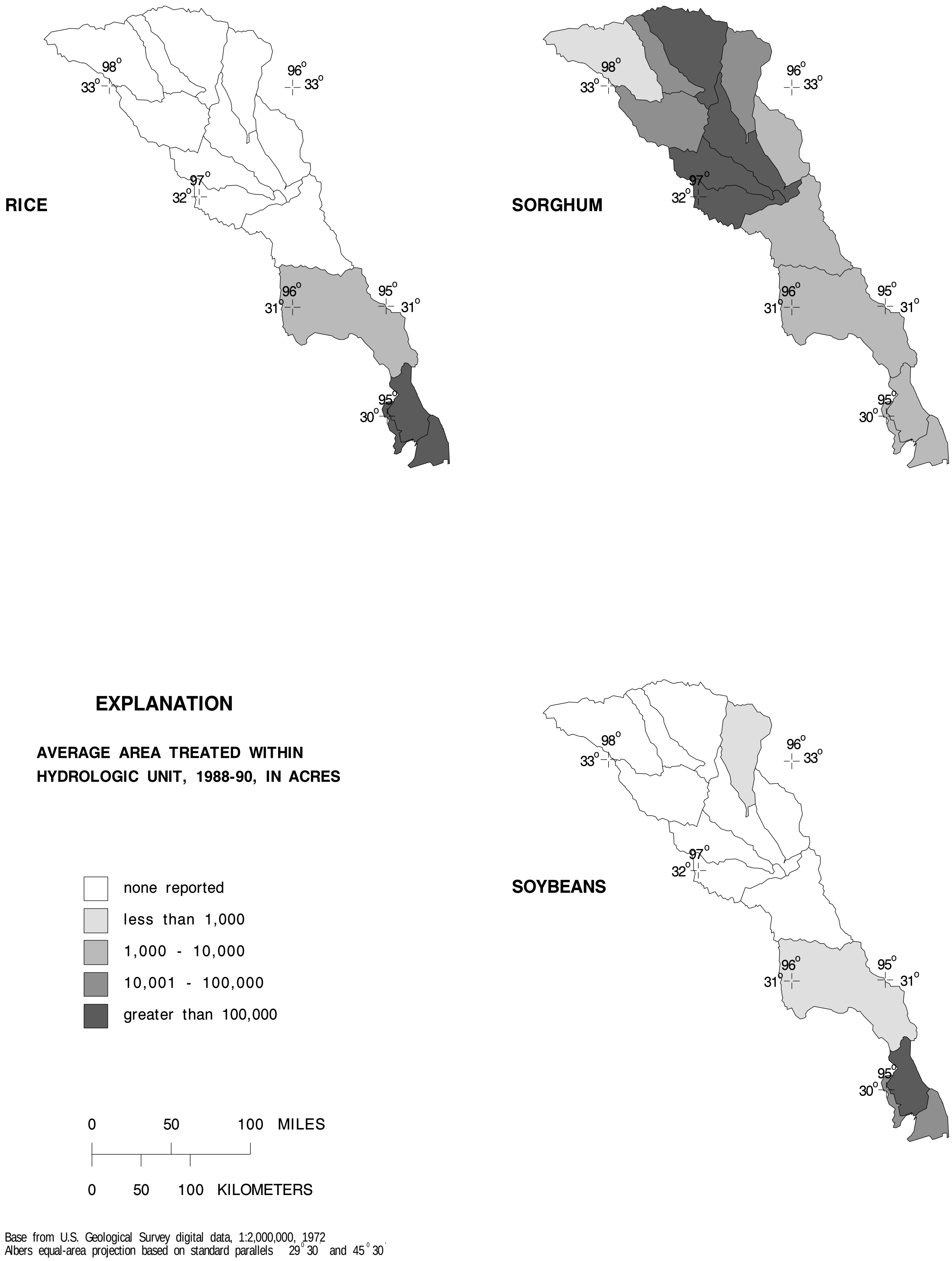


Figure 7. Average areas of rice, sorghum, and soybeans treated during 1988–90.

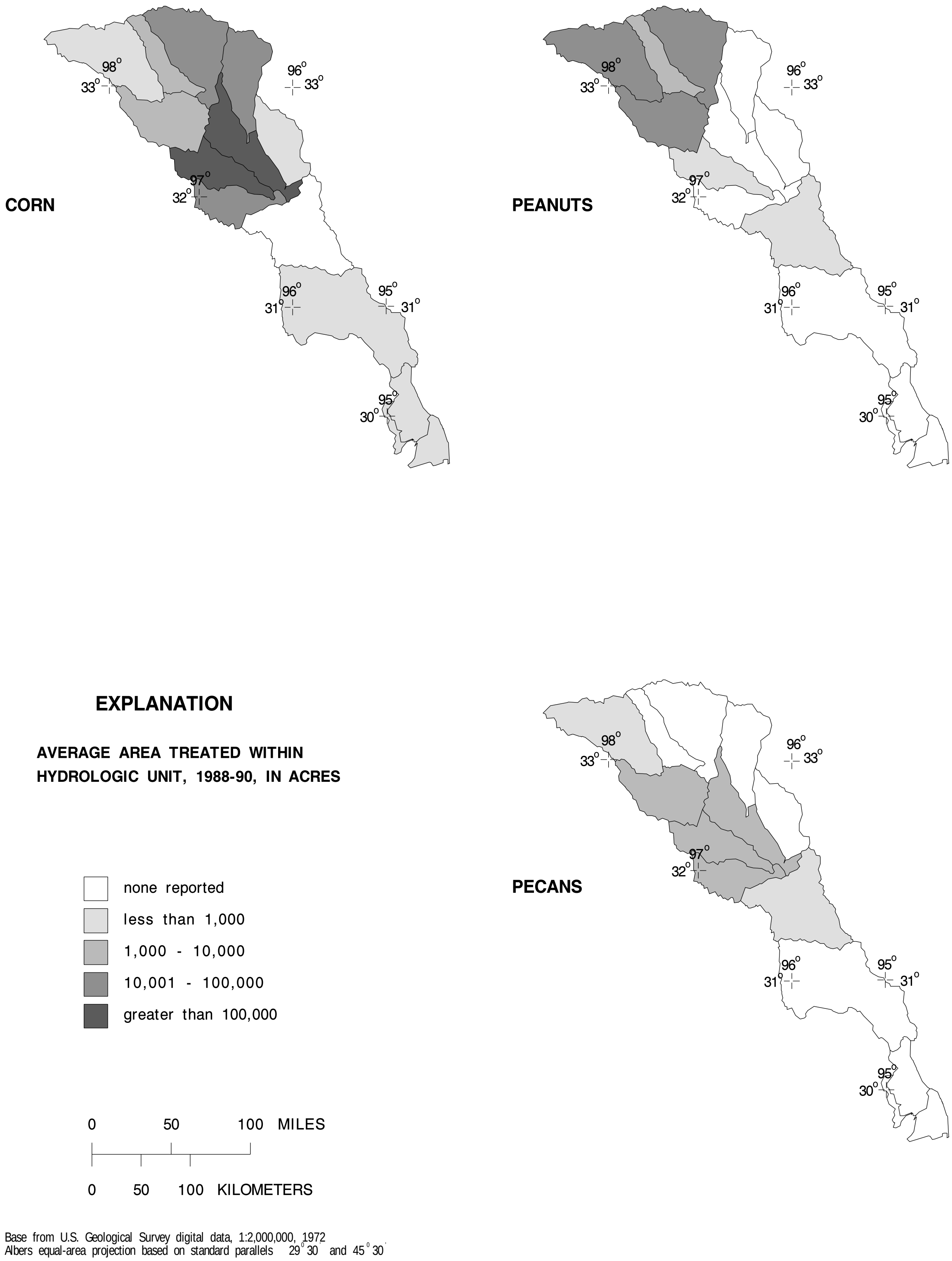


Figure 8. Average areas of corn, peanuts, and pecans treated during 1988–90.

Table 2. Average crop areas treated and number of 24 most-used pesticides applied in the study unit, 1988–90

[Data from Bill Harris, Texas Agricultural Extension Service, written commun., 1991.]

Crop name	Average areas treated annually (acres)	Number of 24 most-used pesticides applied
Alfalfa or other hay	215,020	11
Barley	3,000	1
Corn	127,620	12
Cotton	519,870	14
Cowpeas	200	0
Grapes	260	3
Melons	4,100	1
Oats	6,650	8
Peanuts	23,110	10
Pecans	8,720	6
Rice	265,430	5
Rye	40	1
Sorghum	261,350	16
Soybeans	172,131	8
Vegetables	1,420	3
Watermelons	7,530	3
Wheat	541,250	9

The major crop-group classification as applied to the Trinity River Basin study area is shown on figure 9. This classification indicates that a substantial part of the agricultural land in the study area is devoted to raising wheat and other grains, sorghum, corn, and cotton.

CHARACTERISTICS AND USE OF SELECTED PESTICIDES

By 1983, the American Chemical Society's Chemical Abstracts Service (Manahan, 1990) had registered over 4 million chemical compounds, most of which were synthetic organic compounds. Environmentally important groups of these compounds include pesticides, phenols, and polychlorinated biphenyls (PCBs). It is estimated that some 600 active ingredients currently are marketed in 45,000–50,000 pesticide formulations (Pait, 1992). These pesticides may enter surface- and ground-water systems from point-source discharges, nonpoint-source runoff, or atmospheric deposition. Once in the water, pesticide fate and distribution are affected by processes including sorption interactions with sediment, accumulation in biota, or transformation. Transformation processes, include photolysis, hydrolysis, biodegradation, and volatilization, act to reduce the concentration of given organic compounds in solution (Smith and others, 1988), but may create other compounds.

Spatial and temporal variations in the occurrence of pesticides in the water column or bed sediments occur as a result of the solubility of the pesticide and the suspended solids concentration. These, in turn, are influenced by the

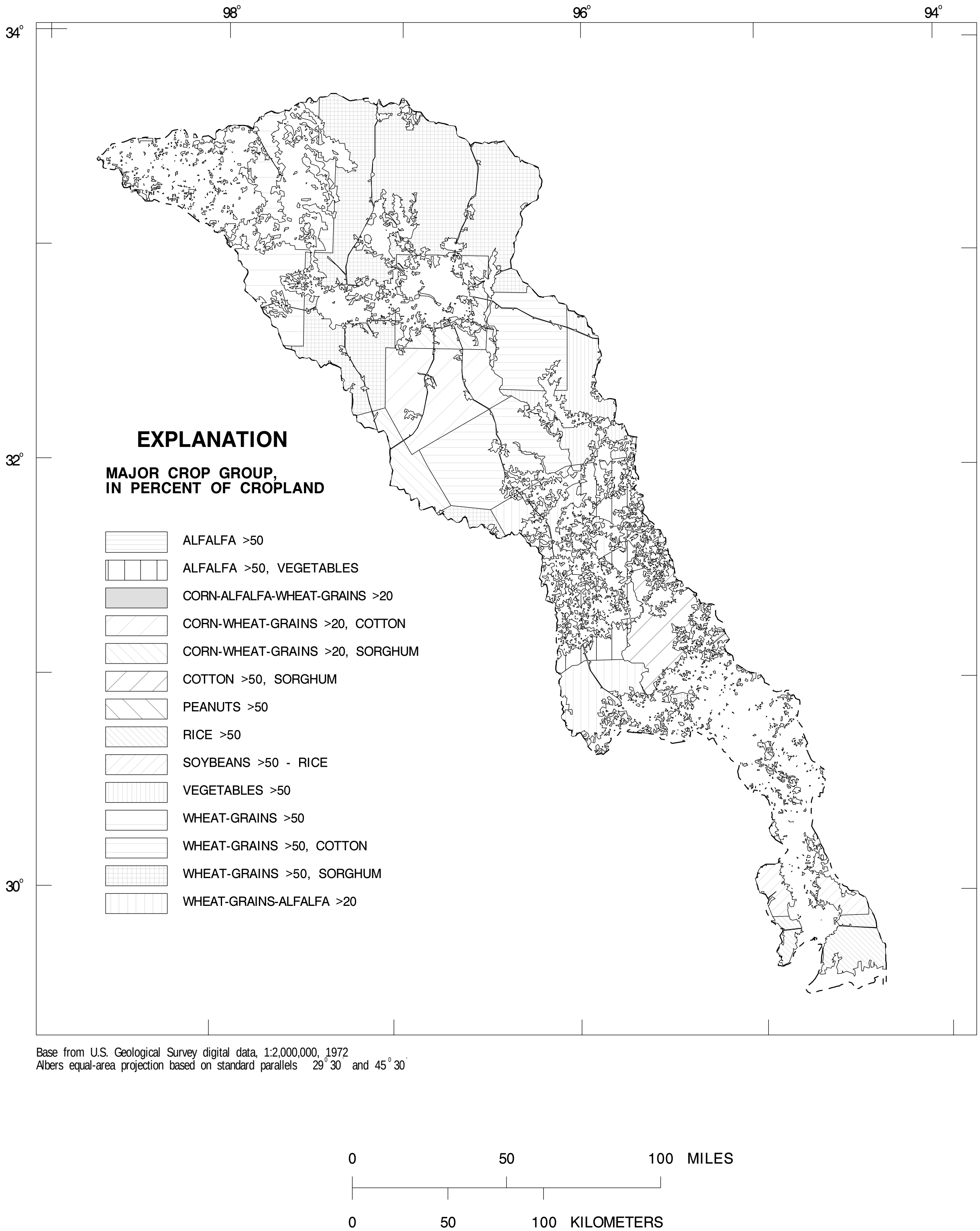


Figure 9. Major crop-group classification.

physical characteristics of the study area, proximity of the source to the stream or aquifer, and the location of reservoirs in the stream network. Pesticides detected in the aquatic environment are influenced further by factors such as toxicity, persistence, and bioconcentration. Consumer preference for any particular pesticide also tends to change over time, as do the regulations governing the use of pesticides. The season in which the pesticide is applied is also a significant factor governing the availability of the pesticide for wash off during storms.

In 1976, approximately 65 percent of pesticide use in the United States occurred in agricultural areas (Gilliom, 1985). Agricultural crops are threatened continuously by air- or soil-borne organisms including bacteria, fungi, insects, nematodes, and weeds. These pests or pathogens may reduce crop yields and be detrimental to crop quality. Disease- or pest-resistant crop species have been and are being developed which can reduce dependence on pesticides, but agriculture is likely to remain dependent on pesticides for the foreseeable future. Little information was readily available about the actual application of pesticides in the Trinity River Basin study area during the late 1960’s and 1970’s. Table 3 contains readily available national usage figures for those organochlorine, organophosphate, triazine, and chlorophenoxy pesticides which were sampled. Overall use of organochlorine pesticides declined from a 63-percent share of all insecticide use in 1964 to less than a 10-percent share in 1982 (Gilliom, 1985). This is due primarily to the cancellation of most organochlorine pesticides for farm use because of concerns over their persistence in the environment. A comparison of use on farms in 1982 with total use in 1981 shows that by 1982, methoxychlor and toxaphene were the only organochlorine pesticides being used on farms.

Data in table 3 indicate that many of the organophosphate, triazine, and chlorophenoxy pesticides in use during the 1970’s were still in use nationwide in 1981. More recent information (Bill Harris, written commun., 1991) indicates that many of these pesticides still are used in the study area, in particular diazinon, malathion, parathion, and methyl parathion. Table 3 shows that 23 million pounds of 2,4–D, a chlorophenoxy pesticide, were used on farms during 1982, and that total use was 60 million pounds in 1981. This indicates that, assuming total use of 2,4–D in 1982 was equal to total use in 1981, agricultural use accounted for 38 percent of the total use nationally. This means that current estimates of total 2,4–D use in the study area based only on agricultural use are likely to be substantially lower than the actual total use. This also would be true for diazinon and malathion.

Selected characteristics of pesticides more recently applied in the study area (1988–90) are listed in figure 10. This table includes information obtained in part from the Texas Agricultural Extension Service (Bill Harris, written commun., 1991), and in part from publications describing the Soil Conservation Service's I–5 Pesticide Database (Meister Publishing Company, 1991). It was beyond the scope of this report to attempt a detailed discussion of each of the 105 agricultural pesticides identified in the data base as having been applied in the study area. The authors decided to limit the discussion to the 24 most used (by average amounts applied and by average areas treated for the period 1988–90) out of the 105 pesticides listed in the data base with brief discussions of a few pesticides, which were not in the 24 but still notable. These 24 pesticides (fig. 10) accounted for 75 percent of the average amount of agricultural pesticides applied in the study area during 1988–90, and the majority are on NAWQA's national priority sampling list.

One purpose of this report is to aid in the design of the study-unit sampling network by identifying areas in the study area where those pesticides with high surface loss or high leaching potential have been applied in relatively large amounts or over large areas. Those pesticides meeting these criteria would be considered for future sampling. Two properties of pesticides can be used to determine their potential to migrate to surface or ground water: (1) the pesticide’s tendency to sorb onto soil particles, and (2) its resistance to breakdown (or persistence) over time in the soil. Pesticides with strong adsorptive tendencies remain at the soil surface and are not transported by runoff. Pesticides with short

Pesticide class	Active compound	Trade name[1]	Main associated crop(s)	Typical application period												Toxicity category[1]	Average amounts applied (pounds)[2]	Average areas treated (acres)[2]	Rank, average amount applied	Rank, average area treated	Surface loss potential[3]	Leaching potential[3]
				JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC							
Organophosphate insecticide	Dimethoate	Cygon	Cotton, oats, sorghum, wheat, corn													II	266,000	443,000	4	1	3	2
	Methyl parathion	Penncap-M	Cotton, oats, rice, soybeans, watermelons, wheat													I	270,000	343,000	3	3	2	4
	Terbufos[4]	Counter	Corn, cotton													I	123,000	128,000	12	13	2	3
	Parathion	Phoskil	Barley, cotton, oats, sorghum, wheat													I	21,000	397,000	24	2	2	3
	Dicrotophos[4]	Bidrin	Cotton	no longer in use												I	24,000	130,000	23	12	3	2
	Chlorpyrifos	Dursban	Corn, peanuts, pecans, sorghum													II	58,000	85,000	17	18	1	3
	Disulfoton	DiSyston	Corn, cotton peanuts, pecans, sorghum, wheat													I	38,000	70,000	20	20	2	3
Chlorophenoxy and Triazine herbicides	2,4-D[4]	various	Hay, oats, peanuts, sorghum, wheat, turf													I–III	207,000	280,000	6	5	2	2
	2,4-D/ Dicamba[4]	Weed-master	Hay													IV	56,000	59,000	18	22	3	2
	Atrazine[4]	AAtrex	Corn, hay, sorghum													III	69,000	300,000	16	4	2	1
	Prometryn	Caparol	Cotton													II–III	145,000	123,000	10	14	2	3
	Atrazine/ Metolachlor	Bicep	Corn, sorghum													III	283,000	103,000	2	16	2	2
Carbamate insecticide	Carbofuran[4]	Furadan	Corn, cotton, hay, sorghum, rice													I–II	157,000	187,000	8	6	3	1
	Carbaryl	Sevin	Grapes, hay, peanuts, pecans, vegetables, watermelons													I–III	226,000	163,000	5	9	2	3
	Methomyl	Lannate	Corn, cotton, sorghum, soybeans													IV	37,000	109,000	21	15	3	2
	Thiodicarb	Larvin	Cotton													II	35,000	102,000	22	17	2	3

Figure 10. Selected characteristics of the 24 most-used pesticides applied in the study area during 1988–90, by pesticide class.

Pesticide class	Active compound	Trade name[1]	Main associated crop(s)	Typical application period												Toxicity category[1]	Average amounts applied (pounds)[2]	Average areas treated (acres)[2]	Rank, average amount applied	Rank, average area treated	Surface loss poten-tial[3]	Leach-ing poten-tial[3]
				JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC							
Miscellaneous (phosphonate herbicide)	Glyphosate	Roundup	Cotton, grapes, peanuts, pecans, sorghum, vegeta-bles, wheat, peaches													III	89,000	59,000	15	23	1	3
Miscellaneous (Chloracetamide herbicide)	Metolachlor[4]	Dual	Corn, cotton, peanuts, sorghum, soybeans													III	283,000	169,000	1	8	2	2
Miscellaneous (acetanilide)	Alachlor	Lasso	Corn, soybeans													III	156,000	82,000	9	19	2	2
Miscellaneous (Benzothiodiazole herbicide)	Bentazon	Basagran	Soybeans, peanuts, rice													III	49,000	68,000	19	21	3	2
Miscellaneous (Dinitroanaline herbicide)	Trifluralin	Treflan	Corn, cotton, peanuts, soybeans, vegeta-bles, watermelons, wheat													IV	139,000	160,000	11	10	1	3
Miscellaneous (Inorganic acid defoliant)	Arsenic acid	Dessicant L-10, DSMA	Cotton													I	162,000	159,000	7	11	2	3
Miscellaneous (Trichlorpicolinic acid herbicide)	Picloram[4]	Tordon	Hay													IV	90,000	175,000	14	7	3	1
Miscellaneous (Thiocarbamate herbicide)	Thiobencarb	Bolero	Rice													III	107,000	36,000	13	24	2	3

[1] Meister Publishing Company, 1991; Category I is highest toxicity.

[2] Bill Harris, written commun., 1991.

[3] Soil Conservation Service I–5 Pesticide Database (Meister Publishing Co., 1991); 1 is smallest potential.

[4] Most likely to contaminate ground water in the State.

Figure 10.—Continued.

Table 3. Usage data for organochlorine, organophosphate, triazine, and chlorophenoxy pesticides in the United States, 1966–82

[Modified from Gilliom and others, 1985. do., ditto; n.r., none reported]

Active ingredient	Type	Main uses and sources	Use on farms (million pounds per year)				1981 total use (million pounds per year)
			1966	1971	1976	1982	
2,4–D	Chlorophenoxy herbicide	Wheat, rangeland, general purpose	4.0	31.0	38.0	23.0	60.0
2,4,5–T	do.	Rice, rangeland, general purpose	.8	n.r.	n.r.	.2	2.2
2,4,5–TP (Silvex)	do.	Sugar cane, rice, rangeland	n.r.	n.r.	n.r.	n.r.	.4
Aldrin	Organochlorine insecticide	Corn	15	7.9	.9	n.r.	0
Atrazine	Triazine herbicide	Corn	24	54	90	76	92
Chlordane	Organochlorine insecticide	Corn, termites, general purpose	.5	1.9	n.r.	n.r.	9.6
DDT	do.	Barley, cotton, oats, sorghum, wheat	27	.14	n.r. (cancelled 1972)	n.r.	0
DDD	do.	Fruits and vegetables, degradation product of DDT	2.9	.2	n.r. (cancelled 1972)	n.r.	0
DDE	do.	Degradation product of DDT and DDD	n.r.	n.r.	n.r.	n.r.	0
Dieldrin	do.	Termite control, degradation product of aldrin	.7	.3	n.r. (most farm use cancelled 1974)	n.r.	0
Diazinon	Organophosphate insecticide	Hay, oats, peanuts, sorghum, wheat	5.6	3.2	1.6	0.3	9.0
Endrin	Organochlorine insecticide	Cotton, wheat	.6	1.4	.8	n.r.	3
Ethion	Organophosphate insecticide	Cotton	2	2.3	n.r.	n.r.	2
Heptachlor Epoxide	Organochlorine insecticide	Degradation product of heptachlor used mainly on corn	1.5	1.2	.6	n.r.	2
Lindane	do.	Livestock, seed treatment, general purpose	.7	.7	.2	n.r.	.8
Malathion	Organophosphate insecticide	General purpose	5.2	3.6	2.8	1.6	28
Methoxychlor	Organochlorine insecticide	Livestock, alfalfa, general purpose	2.6	3	3.8	.6	5
Methyl Parathion	Organophosphate insecticide	Cotton, wheat	8	28	23	11	20
Parathion	Organophosphate insecticide	Wheat, corn, sorghum	8.5	9.5	6.6	4	5

persistence times degrade before traveling any great distance. In figure 10, the surface loss column lists a ranking of the potential of the pesticide to run off of the application area into nearby surface water. This ranking is based on the pesticide’s sorptivity and soil persistence, soil type, and slope. A rank of one represents the smallest potential for surface loss, and a rank of three the largest potential. The leaching potential column shows a ranking of the potential of the pesticide to leach into ground water, based on the pesticides properties of sorbtion and persistence, on soil characteristics, and on depth to ground water. A rank of one represents the smallest leaching potential, and a rank of three the largest potential. The toxicity category column is a ranking of the pesticide's toxicity to humans according to a system devised by the American Association of Pest Control Officials (Meister Publishing Company, 1991), where a rank IV pesticide is thought to be the least toxic to humans, and a rank I the most toxic. This toxicity ranking is more relevant to the risks to humans associated with ingestion than to their behavior in ground or surface water. Figure 10 also identifies pesticides thought by State officials most likely to contaminate ground water in the study area (Dr. J. Collins, Texas Agricultural Extension Service, written commun., 1991). This identification was made based on a co-ranking of average acres applied and large leaching potential.

Seasonality of application is an important factor influencing the occurrence and distribution of pesticides, because it directly affects the amount of pesticide available for washing from cropland during storms. The antecedent moisture content of the soil, which varies seasonally, as well as the time of application of the pesticide relative to storms, largely will control the amounts of pesticide removed from the cropland. Additionally, many of the newer pesticides have lower environmental persistence so that sampling network design and operation must take in to account the timing of pesticide applications in order to provide the most representative samples possible. Figure 10 lists the typical application period for the 24 selected pesticides.

The design of an optimum pesticide sampling network at the study-unit level, which will support the synthesis of data on the national level, is dependent on the assessment of the regional variations which exist in crop types, acres planted, management practices, and in physical and climatic factors. In order to integrate study-unit level findings with national-level findings, some questions that may be asked include “Are there significant differences in the use of pesticides in the study area as compared to national use?” and “Are there significant differences by pesticide class?” Figure 11 shows 1988–90 national use and study-area use of 15 pesticides (selected on the basis of availability of national-use data) applied in the study area. The diagonal line represents equal national and study-area percentages of total use for the 15 pesticides. Differences in use for the selected pesticides may be observed as deviations from the line. The figure shows, in general, use of the selected herbicides during 1988–90 was relatively higher in the study area than in the Nation, and use of the selected insecticides in the study area was relatively lower than national use.

Figure 12 shows the total pesticides applied by crop and the total crops treated by each of the 24 most-used pesticides in the study area for the period 1988–90. Sorghum was treated with the largest number of pesticides, with cotton, corn, and hay also having appreciable numbers of pesticides applied.

Organochlorine Pesticides

Organochlorine pesticides are characterized by their high persistence in the environment, low solubility in water, and tendency to sorb to particulates in soil, water, and bed sediment (Gilliom and others, 1985). The use of organochlorine pesticides on farms has decreased steadily over the years due to decreasing effectiveness and regulatory restrictions. DDT, one of the most heavily used organochlorine pesticides, was cancelled in 1972. Farm use of other organochlorine pesticides has steadily declined in the study area. No organochlorines are known to be used currently in agriculture in the study area (Bill Harris, written commun., 1991), having been

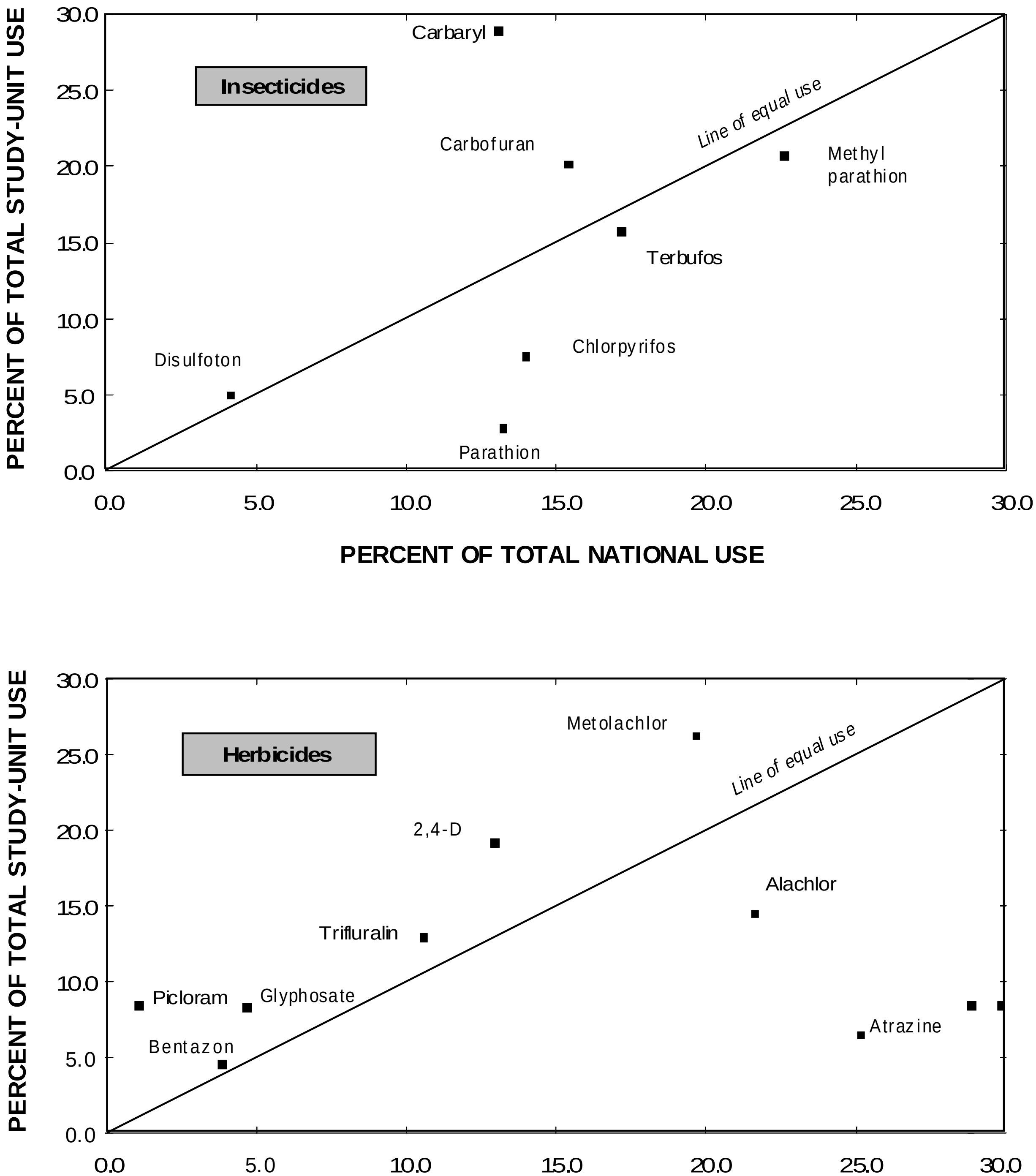


Figure 11. National and study-unit use of 15 selected pesticides, 1988–90.

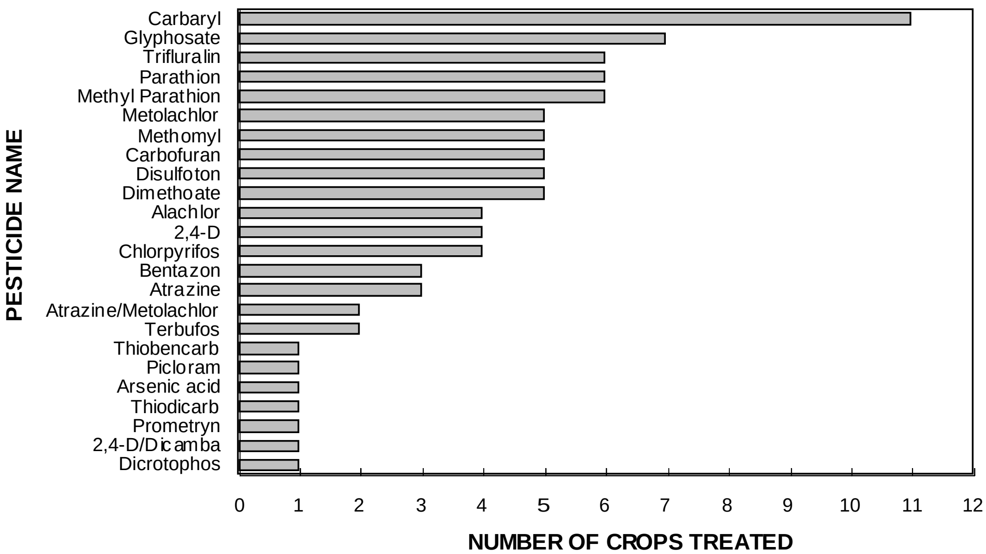


Figure 12. Number of crops treated by 24 most-used pesticides during 1988–90.

replaced by organophosphate or carbamate pesticides.

Organophosphate Pesticides

As a class, organophosphate pesticides are much less persistent in the environment and more water soluble than the organochlorine pesticides. In general, these pesticides tend not to accumulate in bed sediment or tissue but are highly toxic to aquatic organisms, especially crustaceans (Pait, 1992). Organophosphate use is declining steadily nationwide, but continues to be used widely in the study area. For example, methyl parathion, which is applied on cotton, alfalfa, rice, soybeans, vegetable crops, and potatoes, was the third most heavily used pesticide in the study area during 1988–90 (fig. 10). Geographic distribution of the average pounds of methyl parathion is shown on figure 13. This pesticide is used to control boll weevils and other biting or sucking insects, and it is applied throughout the year.

Diazinon, an insecticide available since 1954, is used in the study area to control soil insects and nematodes in turf, pests on fruit and vegetables, and on rangeland and pasture for grub, fire ant, and fly control. Some 3,000 pounds of diazinon were used in agriculture during 1988–90. Although not among the 24 most-used agricultural pesticides, diazinon is important because of its widespread urban use. Diazinon is used in urban areas on lawns to control grubs, fire ants, and fleas, but no information was readily available on application amounts in nonagricultural areas of the study area. Using the national figures from table 3, it may be observed that agricultural use was a small proportion of total use of diazinon. An estimate of nonagricultural diazinon use based on adjusting these national figures to study-area proportions would indicate that as much as 90,000 additional pounds of diazinon may have been applied in the study area during 1988–90. It is the most persistent of the organophosphate pesticides, however, soil sorption studies indicate that diazinon moves slowly in the soil and is not likely to contaminate

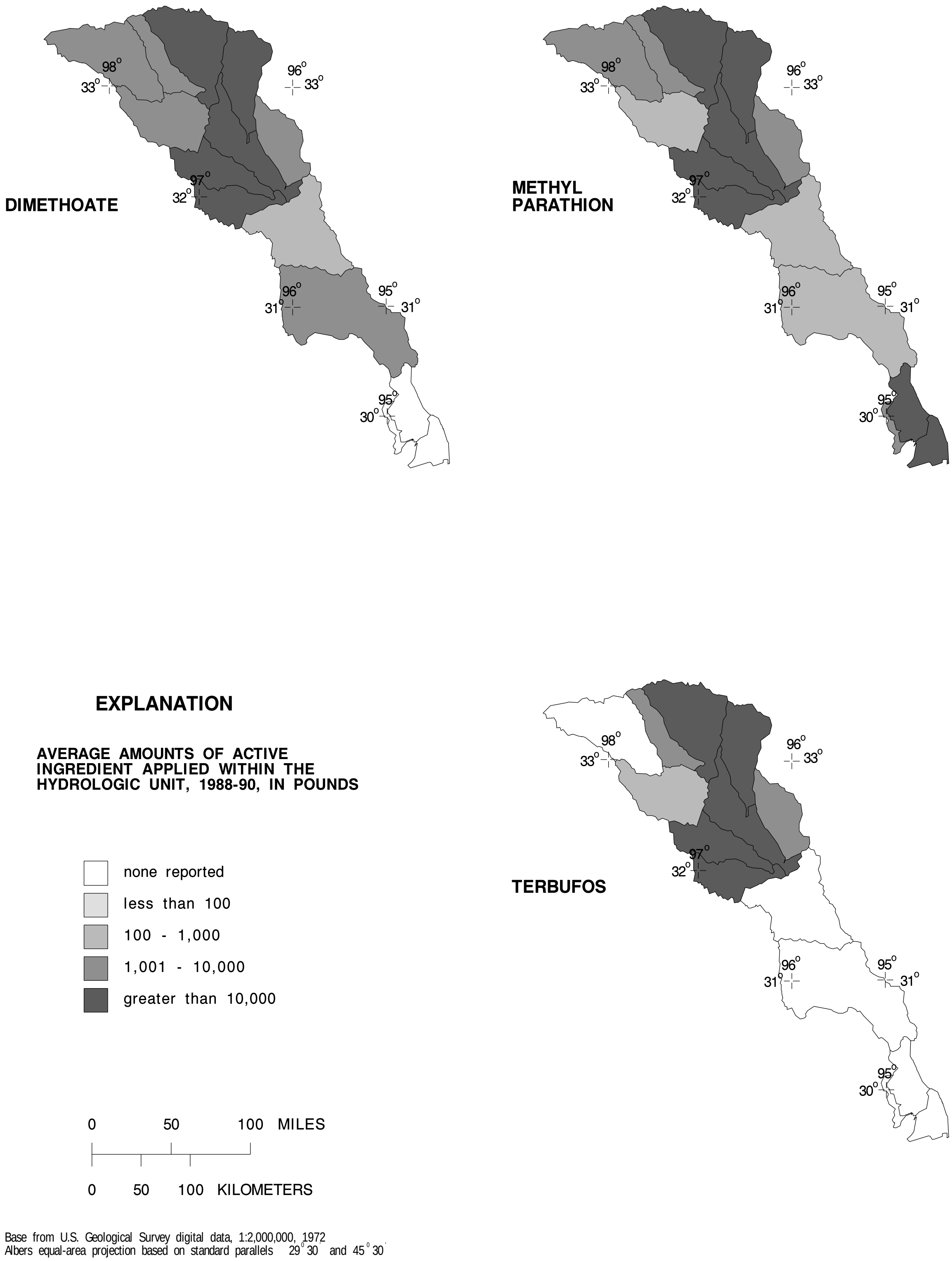


Figure 13. Average amounts of dimethoate, methyl parathion, and terbufos applied during 1988–90.

ground water (Biggar and Seiber, 1987). Diazinon typically is applied during February and March on watermelons, April through July on turf grass, and May through September on peanuts (fig. 10). Because of the widespread use of diazinon in a variety of urban settings, it is likely that diazinon is applied throughout the entire year.

Malathion is another pesticide that is not among the 24 most-used agricultural compounds, but it is important because of urban use. Malathion is currently used in urban settings to control mosquitoes as well as being applied to rice, wheat, alfalfa, and soybeans. It is quite toxic and has been identified as the second leading cause of fish kills in coastal areas (Pait, 1992), due in some cases to spray drift or direct application to the aquatic environment. Malathion is applied during April and May on pecans and April through October on squash. It also is applied May through July on turf grasses.

Parathion (figs. 10, 14) is still one of the most widely used organophosphate insecticides because of its range of insecticidal activity and other suitable physical properties (Murphy, 1986). Because of its high mammalian toxicity, other, less hazardous compounds have begun to take its place. Parathion is the pesticide most frequently involved in fatal poisoning of humans (Murphy, 1986). Figure 11 shows that parathion use in the study area is relatively small compared to national use. Parathion is applied throughout the year on barley, cotton, oats, sorghum, and wheat.

Considering both the average amount applied and the average areas treated, dimethoate (fig. 13), an insecticide used on cotton, corn, and cereal grains, was the most heavily-used (266,000 pounds over 443,000 acres) among the agricultural pesticides applied in the basin. A systemic insecticide, it is used on various fruits and vegetables to control thrips, aphids, and other sucking insects, and as a residual wall spray around farm buildings and other structures to control flies. Dimethoate is applied on corn in April and May, and on other crops November through June (fig. 10).

Chlorophenoxy and Triazine Pesticides

Chlorophenoxy and triazine pesticides are used extensively in the study area as can be seen in figures 15 and 16. These pesticides are intermediate in persistence between the organochlorine and organophosphate types of pesticides, and are highly soluble in water. Triazine pesticides are less soluble and more persistent than chlorophenoxy pesticides. For example, atrazine, with a leaching potential of one (fig. 10), can persist in the soil for 2 to 8 months at common-use rates, as contrasted with 2,4–D which typically lasts less than 1 month according to the Iowa State University Cooperative Extension Service (Meister Publishing Company, 1991). The effectiveness of atrazine is due in part to its persistence in the soil, and therefore it is thought more likely to leach into ground water than the less-persistent pesticides. Atrazine has a high leaching potential and medium surface loss potential (fig. 10). Figure 11 shows that national use of atrazine, as a percentage of the total amount of 15 selected pesticides applied, is about five times greater than study-area use. National use of atrazine is mainly on corn, but study-area use of atrazine is mainly on sorghum, as is the mixture of atrazine and metolachlor (trade name Bicep). Atrazine and Bicep are applied in the study area January through June and atrazine again during November and December.

The herbicide 2,4–D has been available for use in the United States for 35 years. It is a chlorophenoxy herbicide with a leaching potential of 2, which typically lasts less than 6 months in the soil. It is used extensively throughout the study area (fig. 15). It is a unique herbicide which acts to cause uncontrolled cell division leading to necrosis of plant tissues. Study-area cropland use of 2,4–D was 207,000 pounds for the period 1988–90 (fig. 10). U.S. Environmental Protection Agency (USEPA) (Gianessi and Puffer, 1990) estimates of total and noncropland use of 2,4–D nationwide, when adjusted to study-area proportions, indicate that an additional 39,000 to 89,000 pounds may have been applied in noncropland uses. Atrazine applications estimates of only 1,000 additional pounds indicate nearly exclusive cropland use. The herbicide 2,4–D is applied throughout the year in the study area, but the herbicide 2,4-D/Dicamba

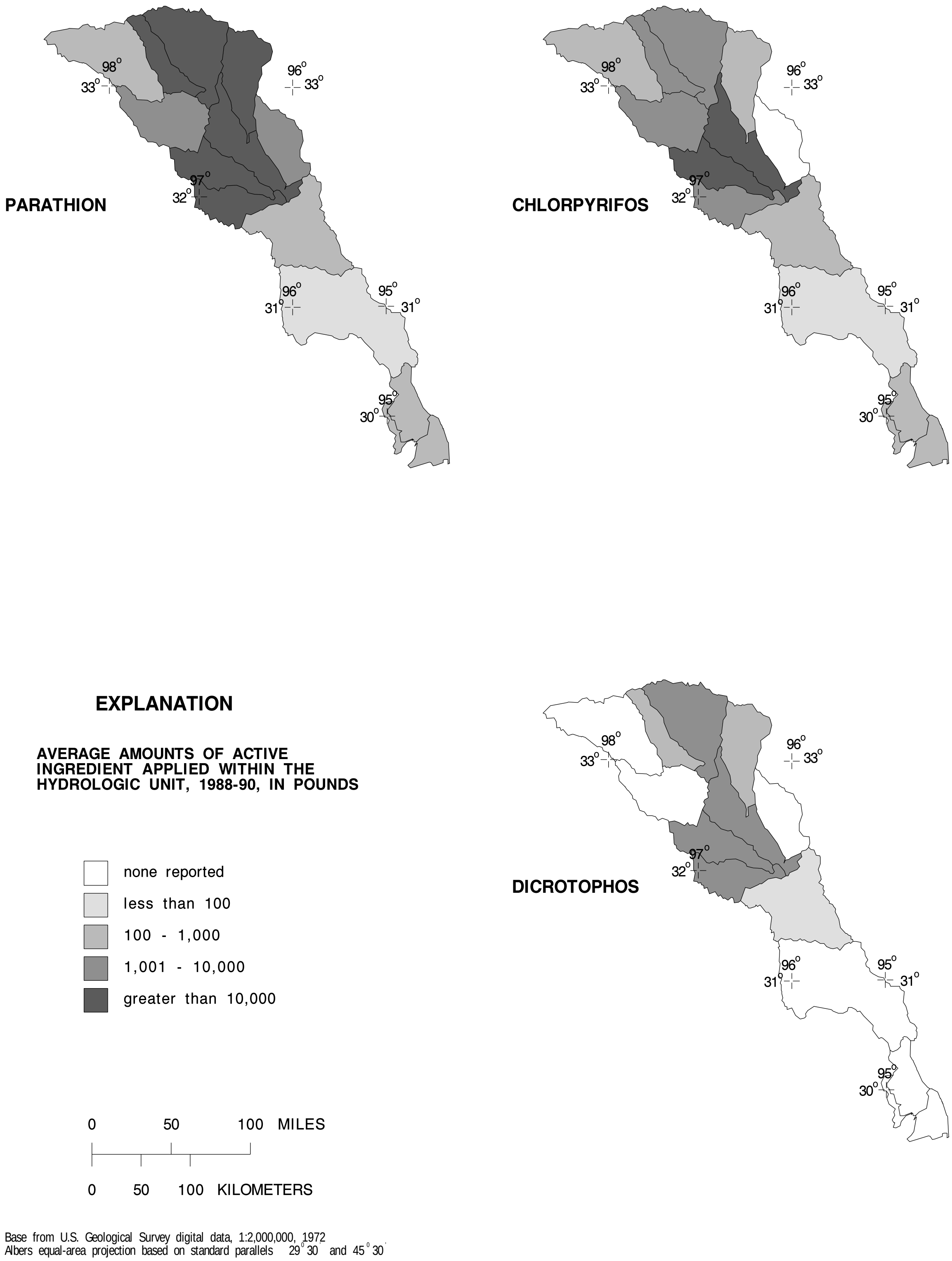


Figure 14. Average amounts of parathion, chlorpyrifos, and dicrotophos applied during 1988–90.

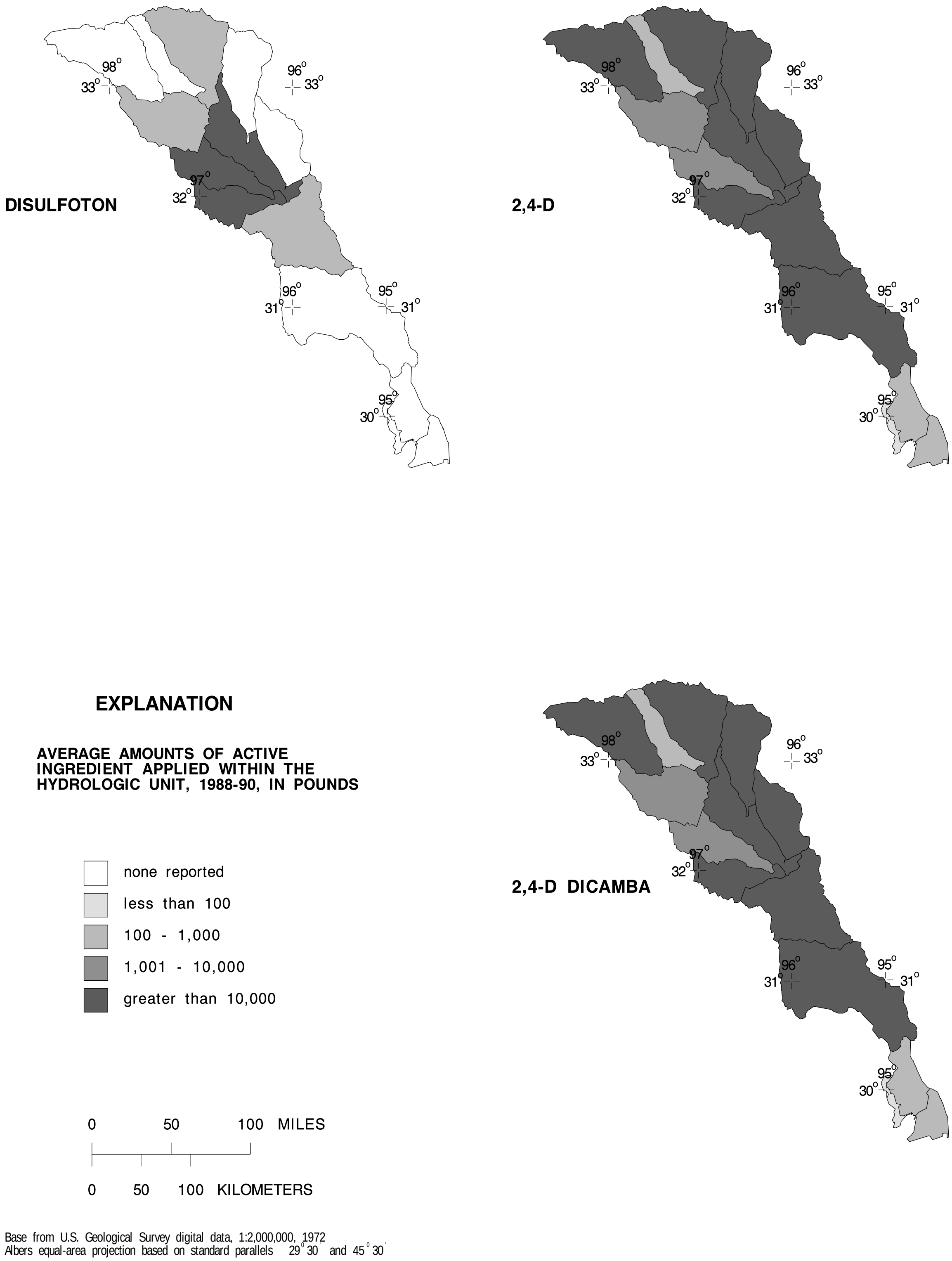


Figure 15. Average amounts of disulfoton, 2,4–D, and 2,4–D/Dicamba applied during 1988–90.

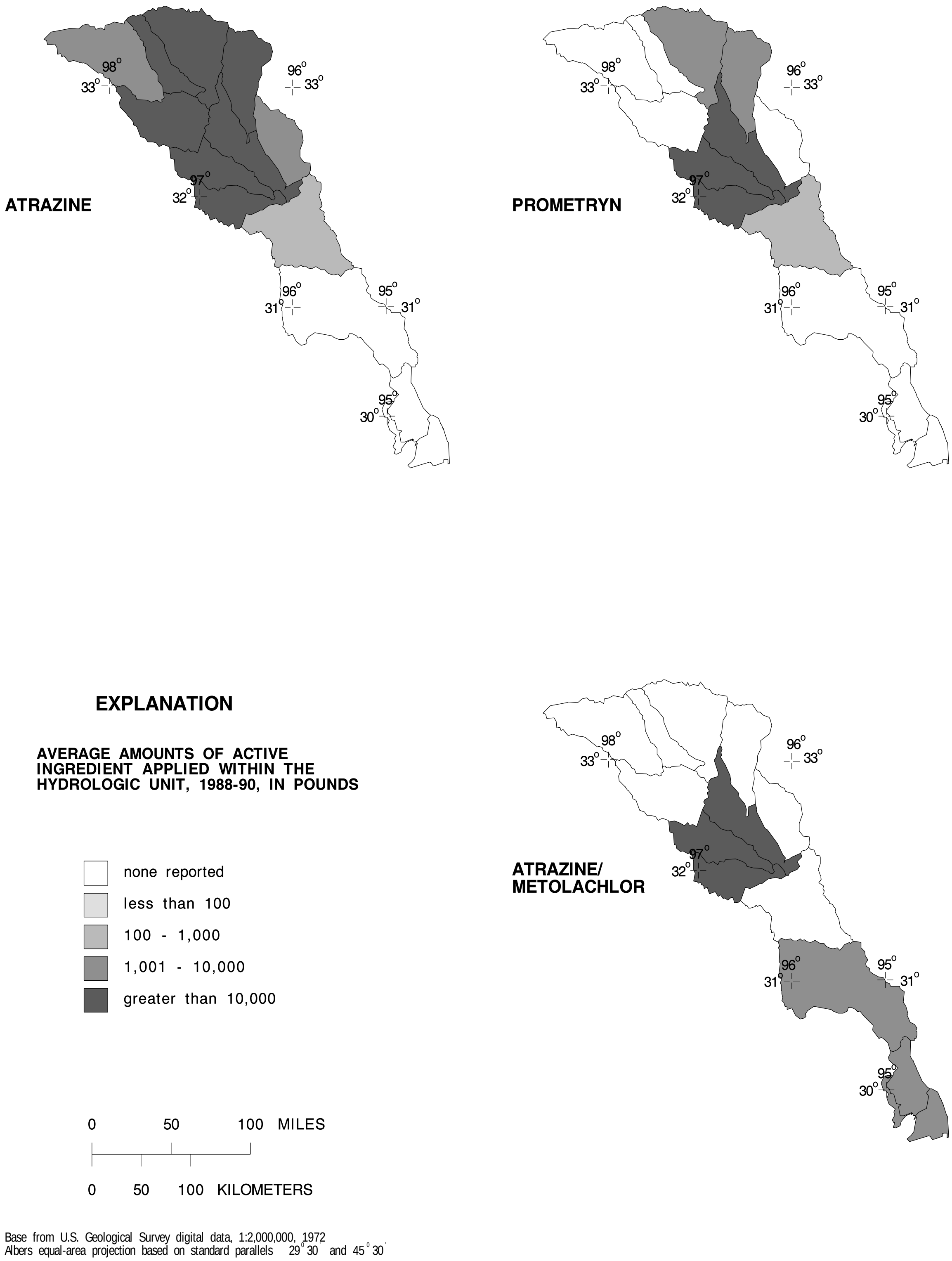


Figure 16. Average amounts of atrazine, prometryn, and atrazine/metolachlor applied during 1988–90.

(trade name Weedmaster) typically is applied January through March and in December. Current estimates of average use indicate some 189,000 to 310,000 pounds of 2,4–D applied in the study area, and about 65,000 pounds of atrazine for the period 1990–91 (Aspelin and others, 1992).

Carbamate Pesticides

The carbamate pesticides most used in the study area are shown on figure 10 and their distributions are shown in figures 17 and 18. The carbamates are distinguished by high water solubility, low persistence, and medium leaching potential. Carbamate pesticides were believed not to present a threat to water supplies or untreated soils; however, aldicarb has been found in ground water on Long Island, New York, and in other locations (Menzer and Nelson, 1986). Although not included in the top 24 by use (27th), aldicarb currently is used in the study area—some 28,500 pounds were applied on 81,000 acres of cotton during 1988–90. Aldicarb is applied on peanuts during April through June in the northern part of the study area.

Carbaryl (fig. 17) is a broad-spectrum insecticide used on cropland, forest land, and rangeland. Major crop uses are on peanuts and hay. Minor crop uses are on grapes, pecans, vegetables, and watermelons. Other uses include flea and tick control on turf, poultry, and pets. Carbaryl is typically applied March through October (fig. 10). Carbofuran (fig. 17) is used on corn during February through May to control insects and nematodes, and also is used on hay, sorghum, and rice. Carbofuran has a high leaching potential. Methomyl (fig. 17) is a broad-spectrum foliar and soil treatment for soybeans, corn, sorghum, and cotton. Molinate, a carbamate herbicide, although not in the top 24 by use, is used in rice-farming areas to control grassy and broadleaf weeds, particularly watergrass. During 1988–90, 114 pounds of molinate were applied on some 114,000 acres in the study area. Thiodicarb (fig. 18) is an insecticide used on cotton.

Miscellaneous Pesticides

Several of the currently used compounds do not fit neatly in one major pesticide class. The herbicide glyphosate (trade name Roundup) is a herbicide widely-used on about eight different crops in the study area, on noncropland agricultural areas, and for aquatic weed control (fig. 18). It has a high surface loss potential, but a low leaching potential. Glyphosate is applied throughout the year in the study area. Metolachlor (fig. 18) is an chloracetamide herbicide, which commonly is mixed with atrazine for preemergent weed control on corn, soybeans, peanuts, sorghum, and cotton. It has medium surface loss and leaching potentials. In the study area, metolachlor is applied February through June and also in September.

Alachlor (fig. 19), an acetanilide herbicide, is used in the study area on corn and soybeans for preemergent control of annual grasses and broadleaf weeds. It has medium surface loss and leaching potentials. Bentazon (fig. 19) is a herbicide used on soybeans, rice, and peanuts. It has a low surface loss potential, and a medium leaching potential. Trifluralin (fig. 19) is an selective preemergent dinitroanaline herbicide with a high surface loss potential, but a low leaching potential. In the study area, trifluralin is used on cotton, corn, peanuts, soybeans, wheat, and watermelons and a variety of vegetables. Trifluralin is applied throughout the year, which might be expected due to the diversity of crops being treated by this pesticide.

Arsenic acid is a herbicide, applied exclusively on cotton, and used as a desiccant to dry and defoliate the cotton plant during August through October. It is an inorganic acid which has medium surface loss potential, and low-leaching potential. The geographic distribution of average pounds applied shown on figure 20 corresponds with the distribution of cotton-growing areas as shown on figure 6. Dimethoate and methyl parathion (fig. 13), disulfoton (fig. 15), and glyphosate (fig. 18) are other pesticides used on cotton (although not exclusively) that show a similar geographic pattern.

Picloram (fig. 20) is used on hay April through June and on deep-rooted weeds in noncropland

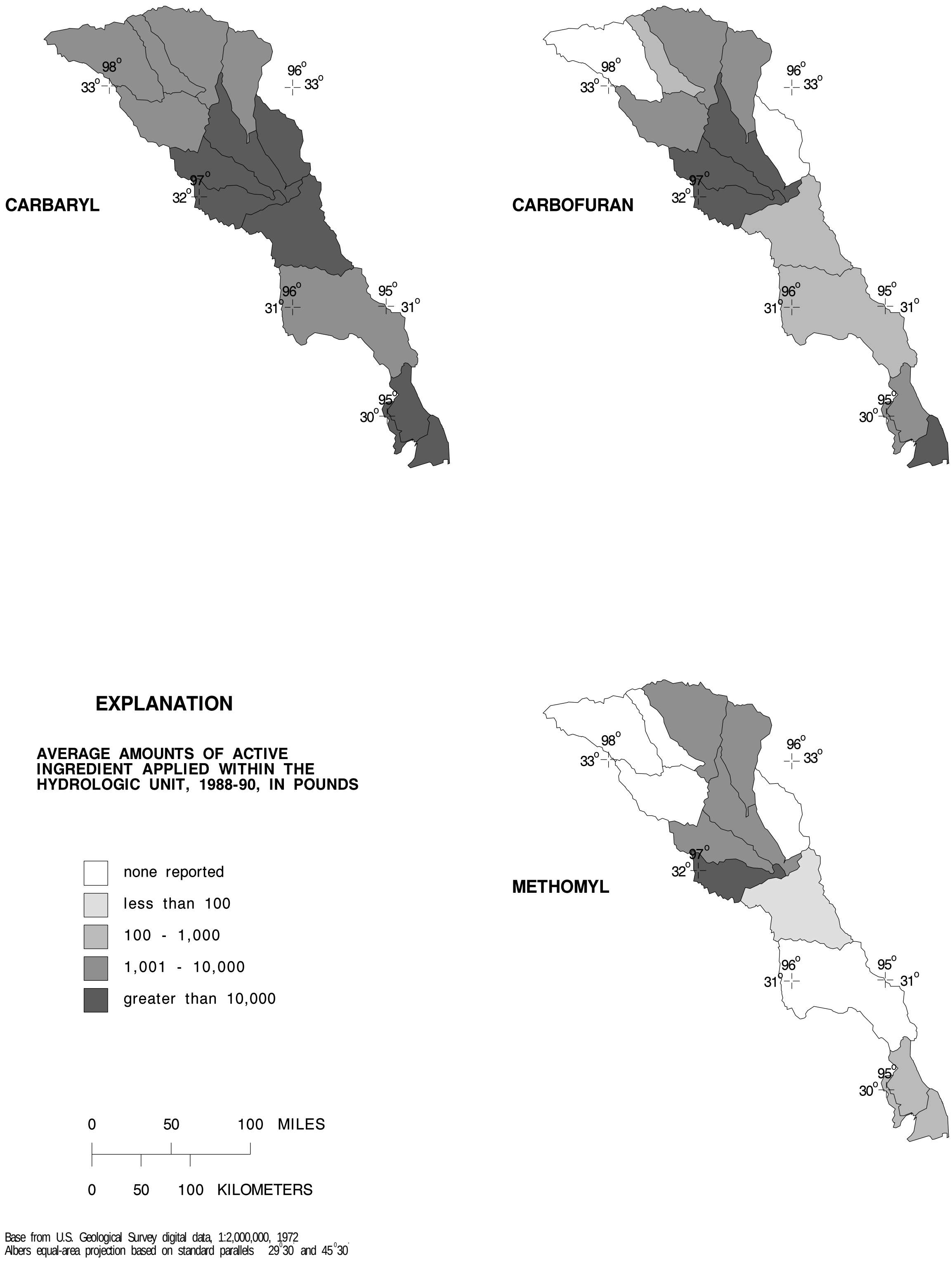


Figure 17. Average amounts of carbaryl, carbofuran, and methomyl during 1988–90.

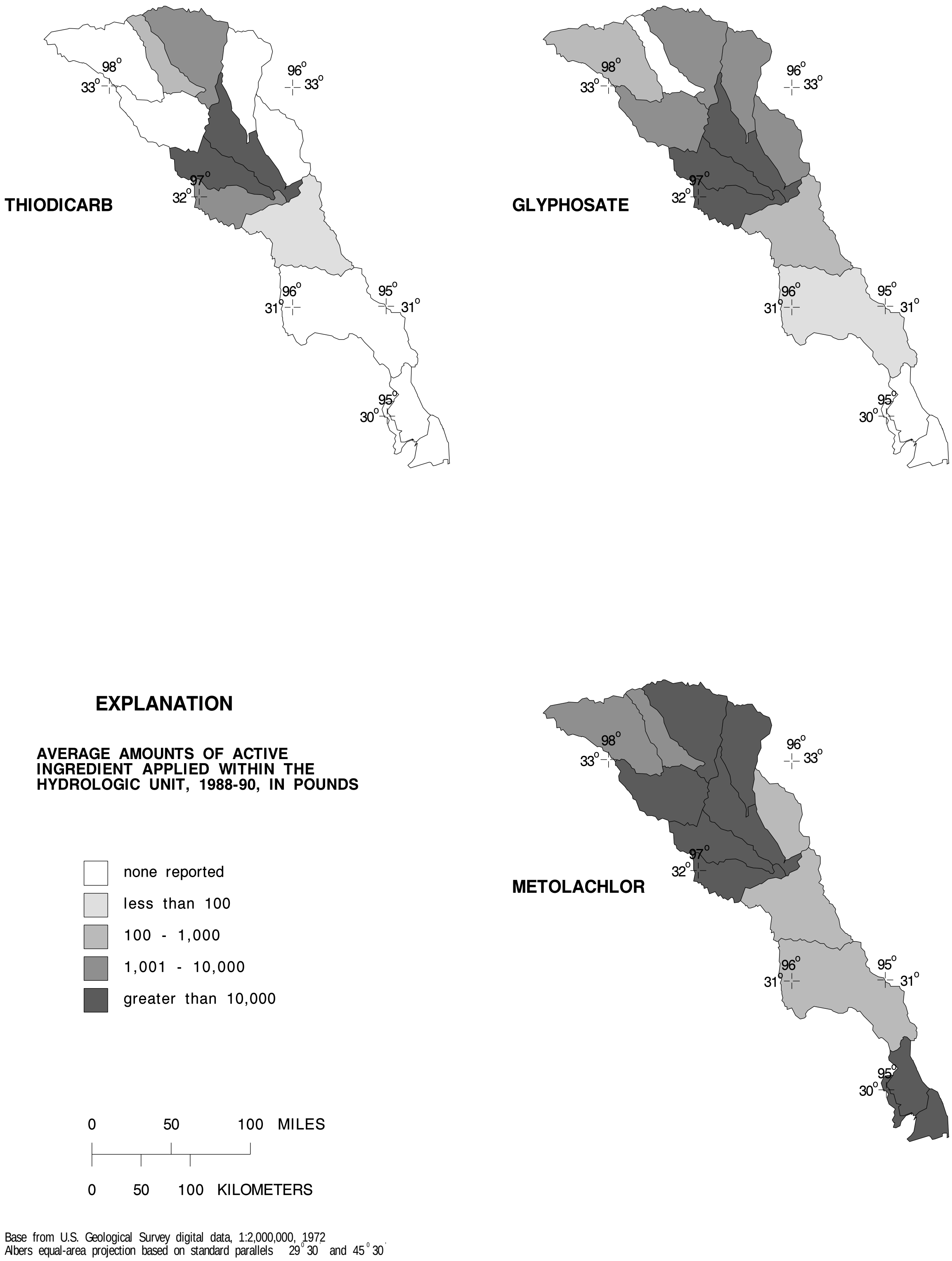


Figure 18. Average amounts of thiodicarb, glyphosate, and metolachlor applied during 1988–90.

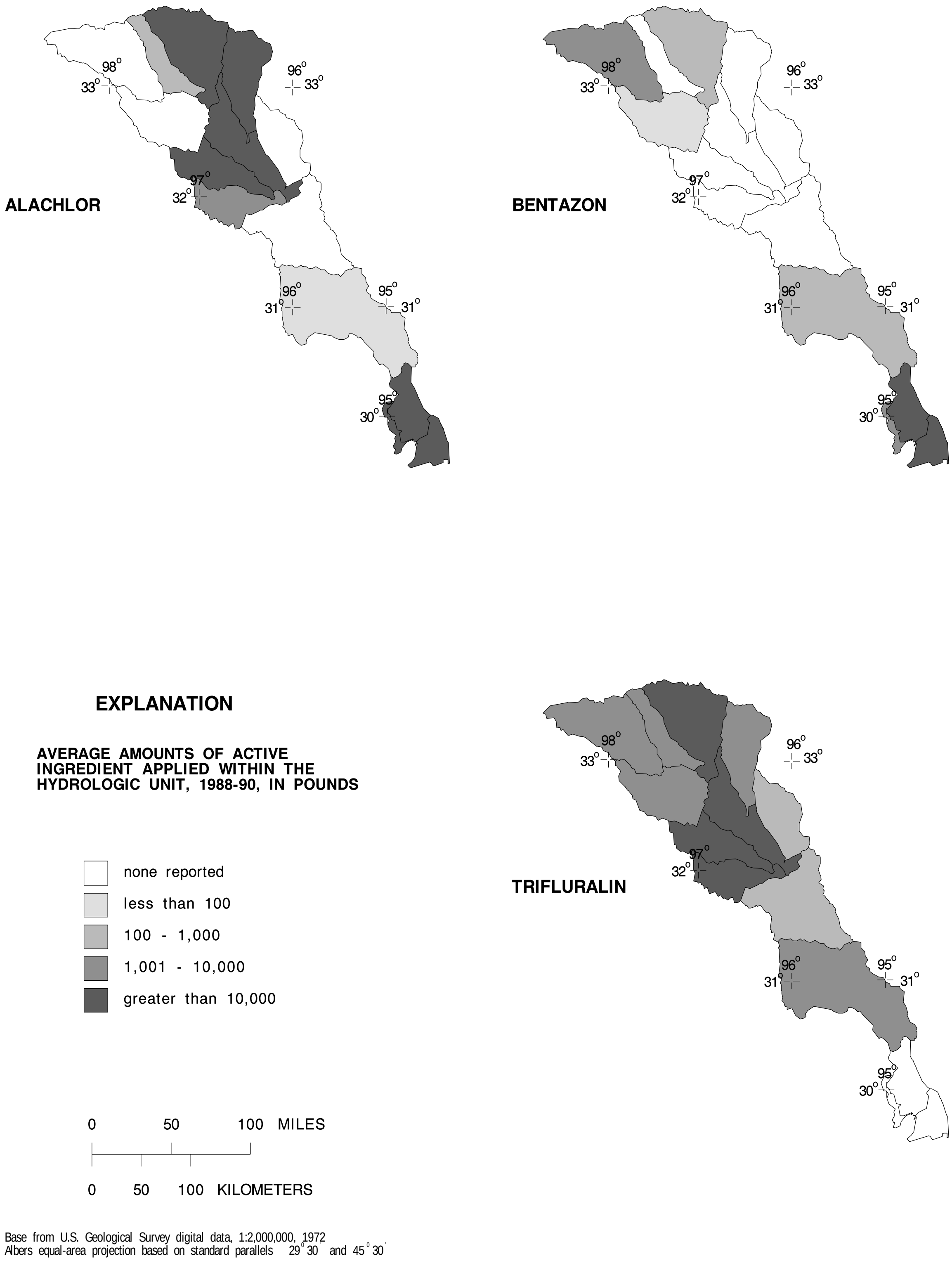


Figure 19. Average amounts of alachlor, bentazon, and trifluralin applied during 1988–90.

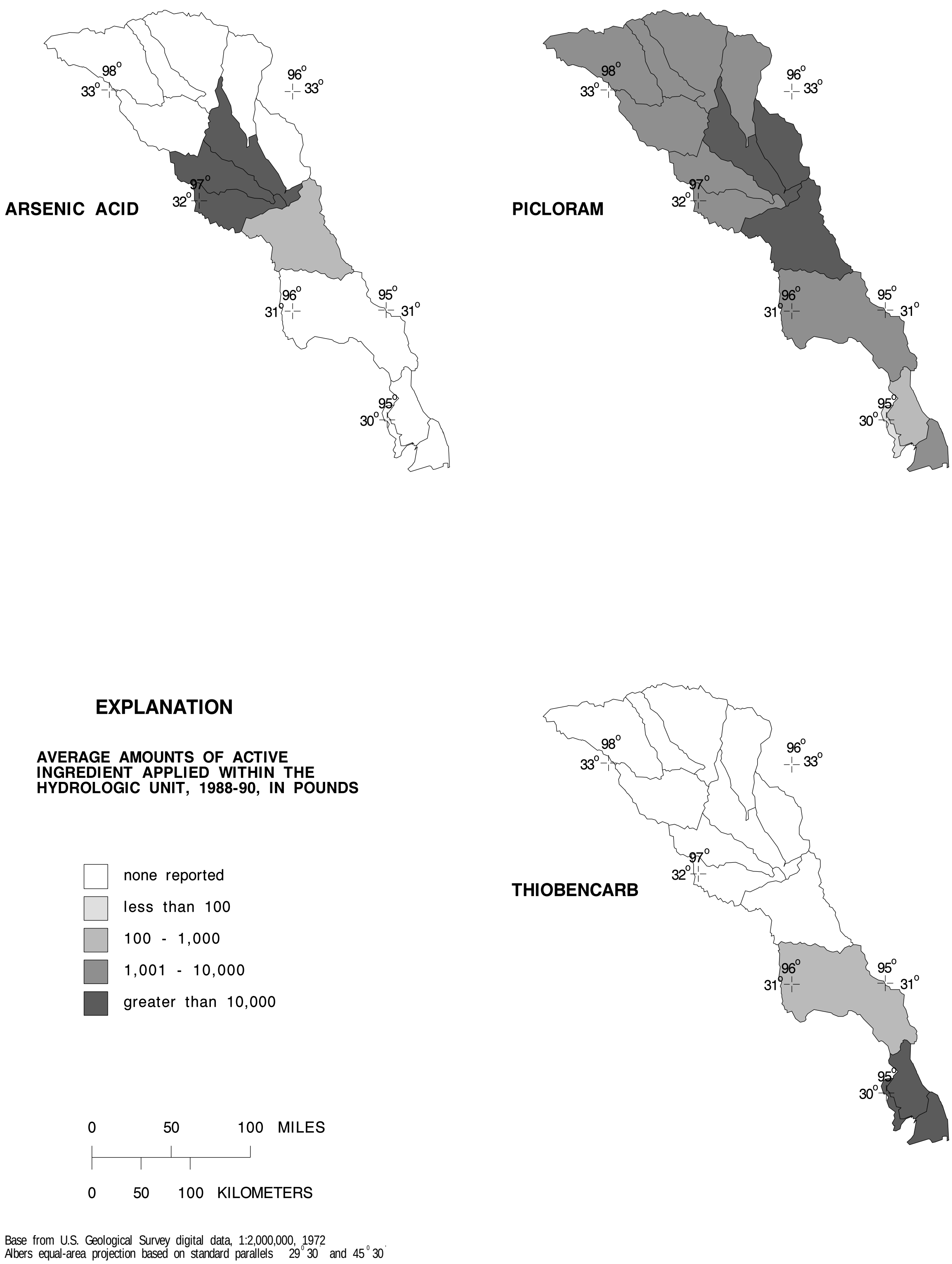


Figure 20. Average amounts of arsenic acid, picloram, and thiobencarb applied during 1988–90.

areas; it also is used along utility lines and other right-of-way areas. It has a low surface loss potential but a high leaching potential. Thiobencarb (fig. 20) is a thiocarbamate herbicide used for preemergent and early postemergent control of weeds in rice farming areas.

Average study-area cropland use of glyphosate (Roundup) was 89,000 pounds for the period 1988–90 (fig. 10). USEPA (Gianessi and Puffer, 1990) estimates of national noncropland use of glyphosate, adjusted to study-area proportions, indicate that total applications in the study area could have been as high as 107,000 pounds for the period 1988–90. Similarly, picloram applications could have been as high as 110,000 pounds, with 90,000 pounds accounted for by cropland use. Figure 10 shows that 283,000 pounds of metolachlor were used on cropland. Estimates of 4,000 to 5,000 pounds of noncropland use of metolachlor show that total applications in the study area would have been between 287,000 and 288,000 pounds, indicating little noncropland use of this pesticide. Total use of trifluralin in the study area is estimated to be 140,000 pounds, or about equal to cropland use, as this pesticide has little use in noncropland areas. Current (1990–91) estimates (Aspelin and others, 1992) indicate that about 160,000 pounds of glyphosate, about 316,000 to 346,000 pounds of metolachlor, and about 129,000 pounds of trifluralin were applied in the study area.

SOURCES OF PESTICIDE ANALYTICAL DATA

Water-quality data for pesticides in the Trinity River Basin are available from a number of local, State, and Federal agencies, as well as universities. The data were collected for a variety of reasons but most large data sets were developed from water-quality monitoring efforts. Data used in this report were limited to that available in computer files or from paper files which could be easily entered into computer files, and to samples with known quality assurance. Sources of pesticide data included two municipalities, two State agencies, two Federal agencies, and two universities. The data sets are discussed below and listed in table 4 (at back of report) along with a brief description of (1) sampling period, (2) pesticides analyzed, (3) detection limit, (4) number of samples, (5) percent of samples with concentrations above the detection limit, (6) general sample-collection purposes, and (7) sample media.

City of Arlington

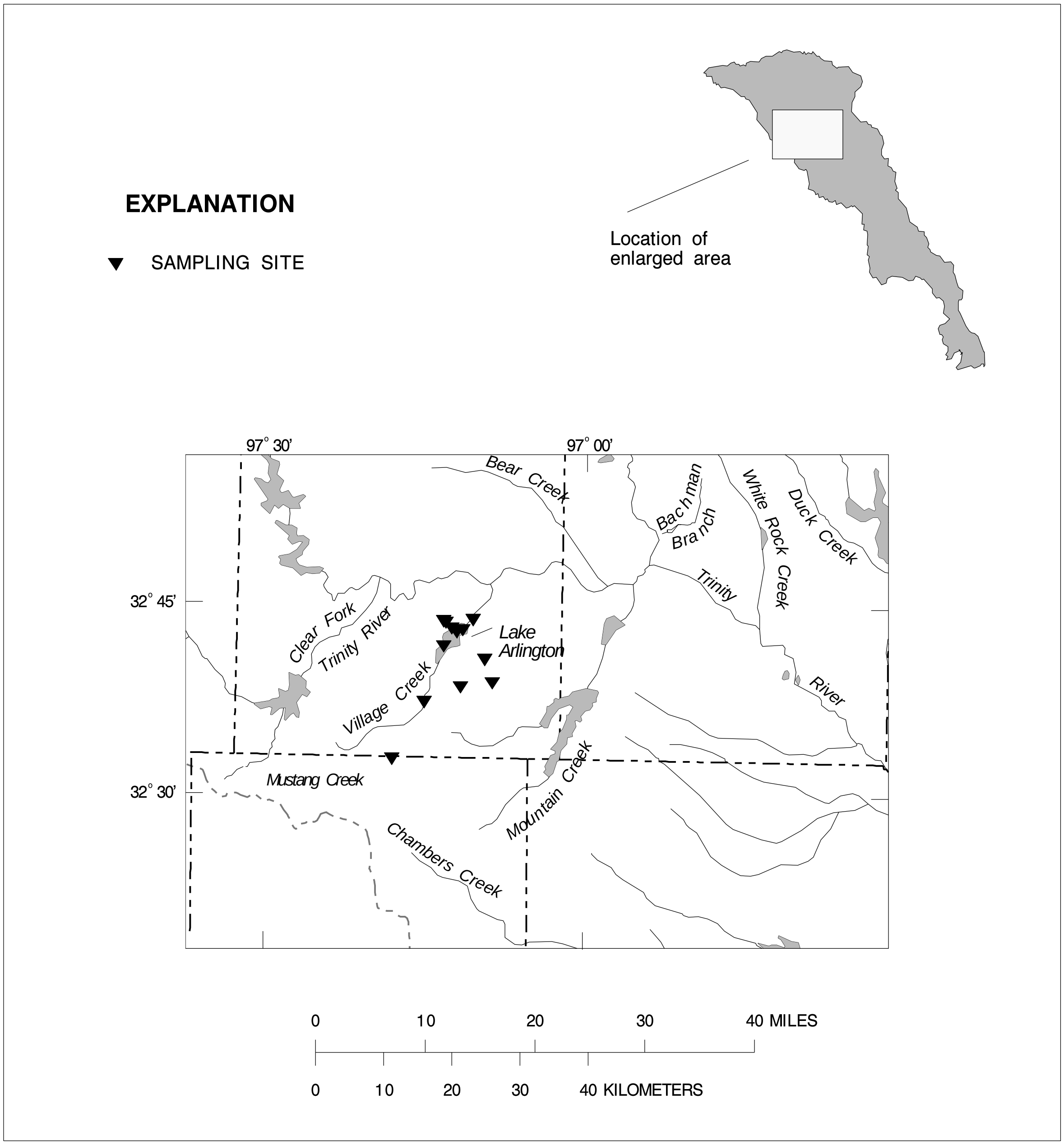
Between 1980 and 1991, the city of Arlington collected samples for 18 pesticides at 12 sites in Lake Arlington and its tributaries (fig. 21). Sampling was conducted as part of routine monitoring of this water-supply reservoir. Analysis of samples was conducted in the city’s laboratory but some detection limits were not available and records of changes in detection limits through time were not kept (Starr Birch, city of Arlington, written commun., 1993).

Dallas Water Utilities

Dallas Water Utilities provided pesticide data from a storm-water runoff study conducted in 1976 and 1977 (Dallas Water Utilities, 1977). Water collected at 17 sites (fig. 22), during two storms in the Dallas area, was analyzed for 18 pesticides.

Texas Parks and Wildlife Department

The Texas Parks and Wildlife Department conducted a study during 1987–88 (Kleinsasser and Linam, 1989) to determine the status of the fish community in the Trinity River between Fort Worth and Livingston Reservoir (fig. 23). The objectives were to examine water quality and fish assemblages in relation to major wastewater discharges, to investigate causes of major fish kills in 1985, and to aid the Texas Water Commission in a use-attainability study of the river between Beach Street in Fort Worth (site 1) and Highway 21 near Trinidad (site 11). As a part of this study, fillets from 36 individual fish and five composite samples of three fish each collected at 19 sites were analyzed for four pesticides.

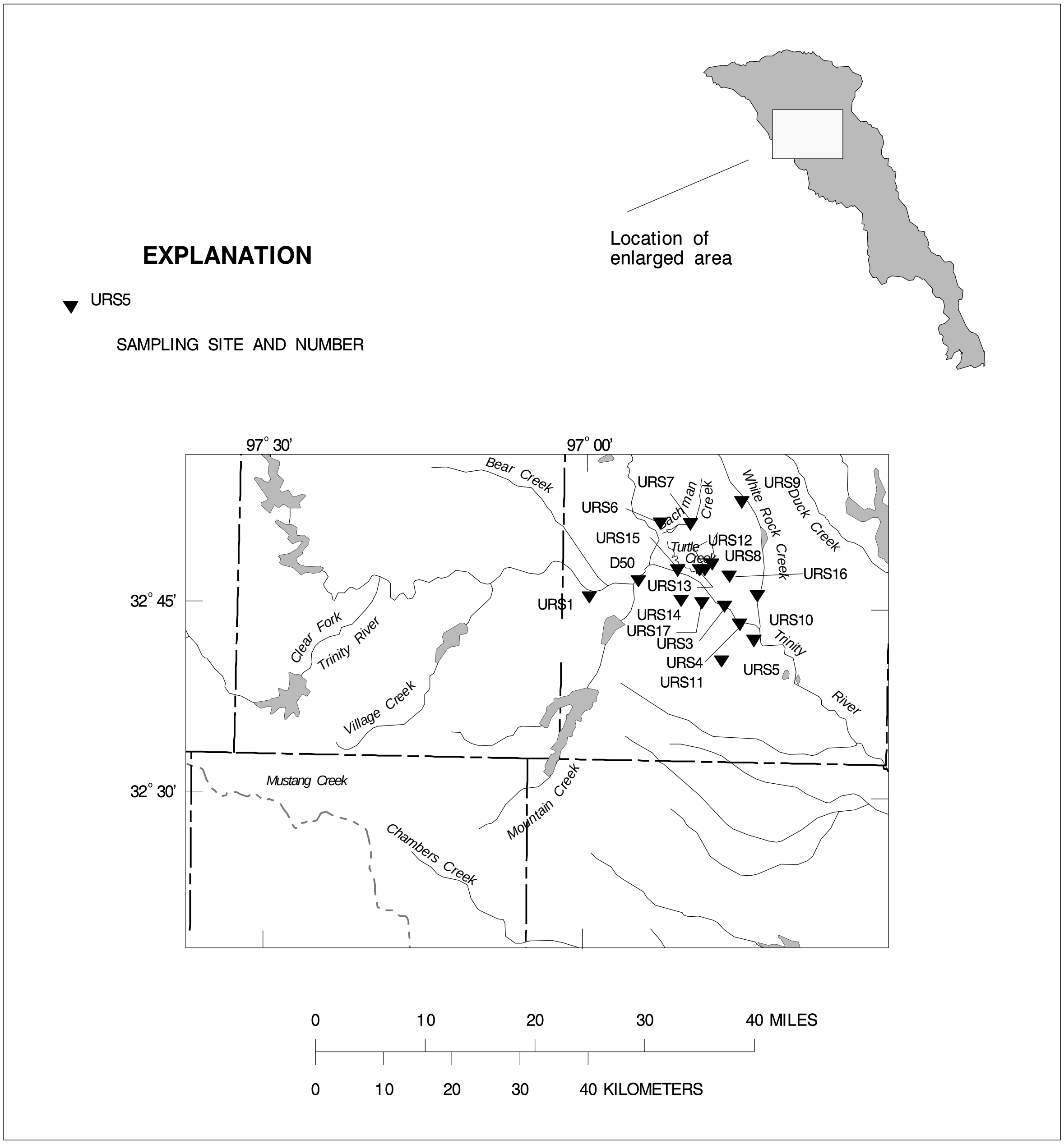


Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers equal-area projection based on standard parallels 29° 30' and 45° 30'

Figure 21. Location of city of Arlington sampling sites for pesticide analyses.

Texas Water Commission

The Texas Water Commission has compiled a data base (Arthur and Ambrose, 1992) for pesticides in ground water which includes data from 1,710 wells sampled for pesticides and (or) arsenic by the Texas Water Commission, Texas Department of Agriculture, Texas Department of Water Resources, Texas Department of Health, Texas Water Development Board, U.S. Geological Survey, and two underground water conservation districts. The data base represents only a few agricultural areas in the State and includes 18 wells sampled for pesticides (29 different parameters) in seven counties in the Trinity River Basin. All of these wells were sampled by the Texas Water



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers equal-area projection based on standard parallels 29° 30' and 45° 30'

Figure 22. Location of selected Dallas Water Utilities stormwater study sampling sites for pesticide analyses.

Development Board (Arthur and Ambrose, 1992) as a part of a statewide characterization of ground-water levels and quality. Some 121 wells in 23 counties in the basin (including the previously mentioned 18) were sampled by Texas Water Development Board for arsenic. Figure 24 shows these ground-water sampling sites.

The Texas Water Commission also collected samples of bed sediment at 51 stations in the Trinity River Basin for 18 different pesticides between 1974 and 1981 (Arthur and Ambrose, 1992). These surface-water sampling sites also are shown on figure 24. This sampling was considered routine monitoring with stations located

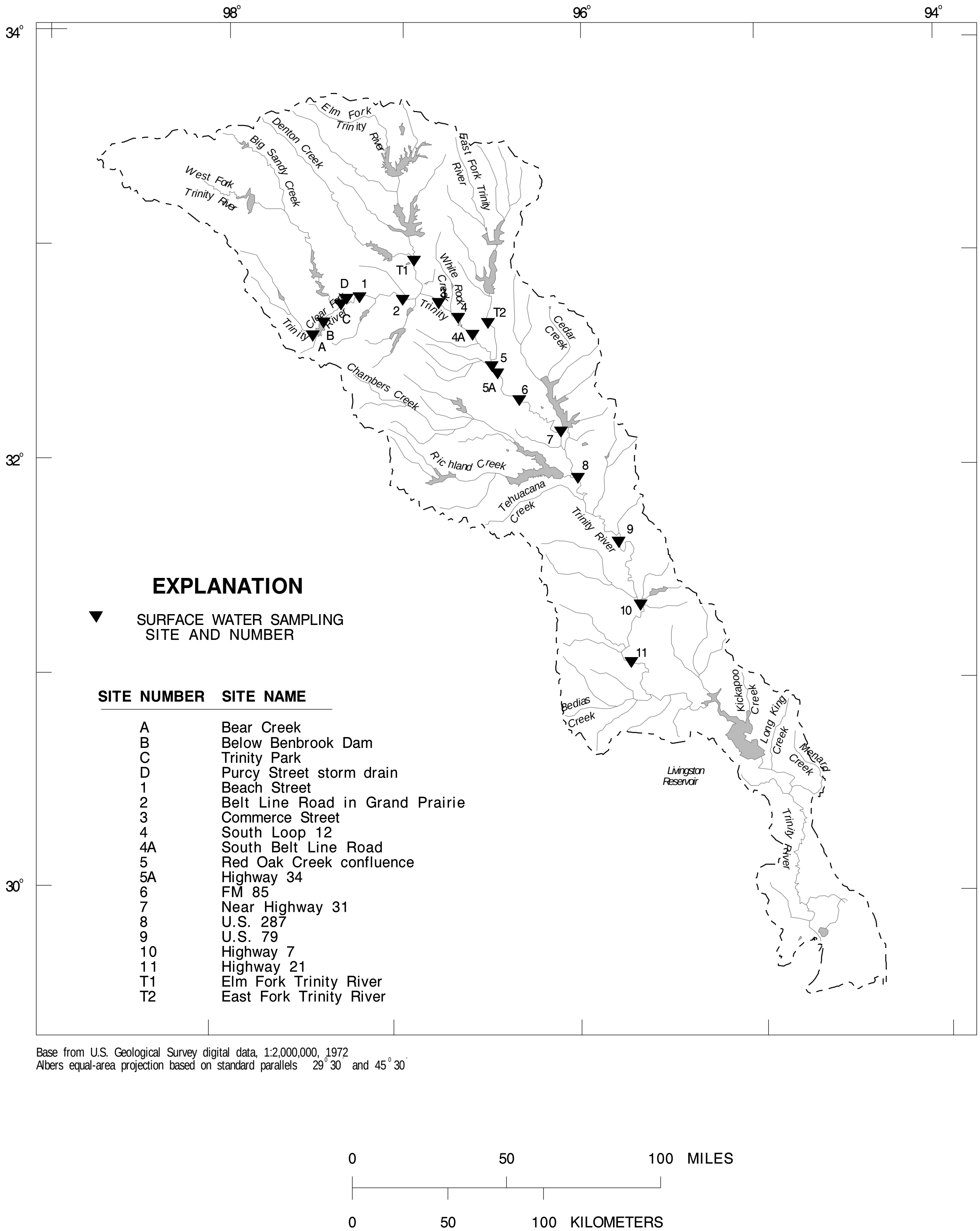


Figure 23. Location of Texas Parks and Wildlife sampling sites for pesticide analyses.

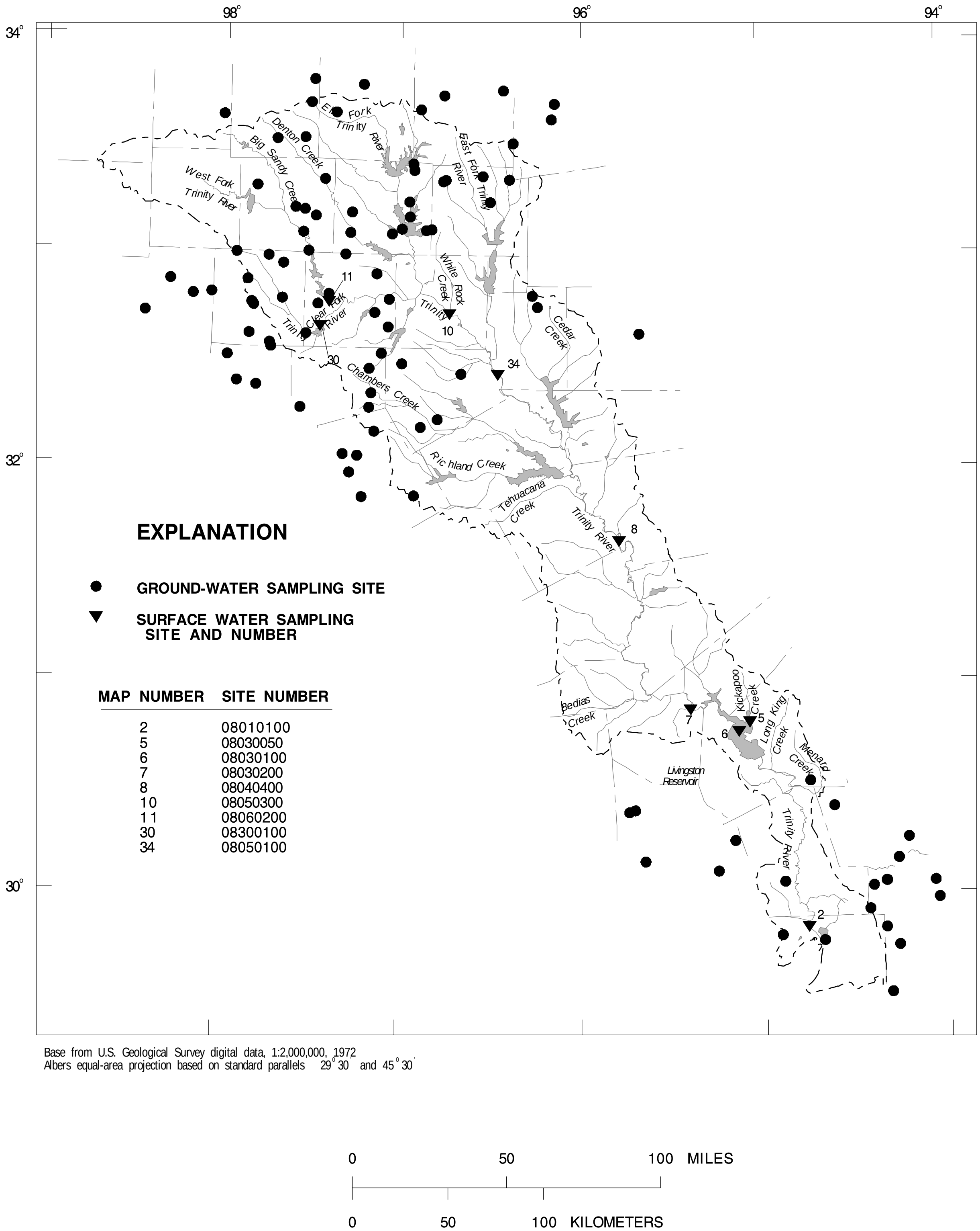


Figure 24. Location of Texas Water Commission sampling sites for pesticide analyses.

downstream of potential sources. These data also included samples for two chlorophenoxy herbicides in water and two organochlorine insecticides in tissues of aquatic organisms. Detection limits were provided for all samples, but limits were highly variable with many different detection limits given for each pesticide. The limits listed in table 4 are only a subset representing typical values.

United States Fish and Wildlife Service

Data from the U.S. Fish and Wildlife Service are from a study of contaminant impacts on Trinity River fish and wildlife (Irwin, 1988). Objectives of the study included identifying (1) which fish and wildlife species are accumulating potentially harmful body burdens of toxic contaminants, (2) locations of chemical “hot spots,” (3) contaminants whose presence is correlated with industrial, municipal, illegal, or residential runoff, (4) initial estimates of the impacts of various types of runoff on fish populations, (5) potential impacts of individual toxic chemicals on Trinity River fish and wildlife, and (6) contaminant information providing insight into potential causes of fish kills. This 1985 study analyzed 64 samples of tissues from fish, turtles, clams, and crayfish for 14 pesticides. Samples were collected at 27 sites from upstream of Fort Worth, through Dallas, to approximately 250 mi downstream (fig. 25).

United States Geological Survey

From 1968 through 1981, the U.S. Geological Survey collected bed-sediment and water samples at six stations (fig. 26) in the Trinity River Basin study area and analyzed the samples for 22 pesticides. Samples were collected and analyzed for 22 pesticides at one additional station (08065800) during the period 1985–88. The samples were collected for routine monitoring of water quality.

University of North Texas

The University of North Texas and the University of Texas at Dallas conducted a water-quality and ecological survey of the Trinity River for the city of Dallas Water Utilities during 1987–88 (Dickson and others, 1989). The objectives of the survey were to document distribution of fish and benthic macroinvertebrates, characterize sediment, assess toxicity of water and sediment, and develop a data base for better understanding of relations between point and nonpoint loadings and fish kills. Bed sediment and water samples were collected quarterly between June 1987 and December 1988 at 12 stations upstream of, in, and downstream from the Dallas-Fort Worth area (fig. 27). Water samples were analyzed for 19 pesticides and bed sediment for 14 pesticides. Additionally, in August 1987 and September 1988, sunfish (*Lepomis* sp.) were collected at each station and analyzed for whole body levels of 11 pesticides (most results are for single fish, with some composites of several small fish included).

University of Texas at Arlington

The University of Texas at Arlington conducted a study of quality of water and bed sediment in the Trinity River for the U.S. Army Corps of Engineers, Fort Worth District (Qasim and others, 1980). The objectives were to develop preliminary data on the quality of water and bed sediment and to determine the mobility of various contaminants when bed sediment was mixed with river water to simulate dredging conditions. Samples of bed sediment and water were taken once at 13 stations from the Dallas-Fort Worth area to downstream of Livingston Reservoir (fig. 28).

REVIEW AND ANALYSIS OF AVAILABLE PESTICIDE DATA

This section presents a review of each agency’s data, and significant findings of monitoring programs operated and investigations conducted during 1968–91. Because each entity involved with the collection and analysis of pesticide data was

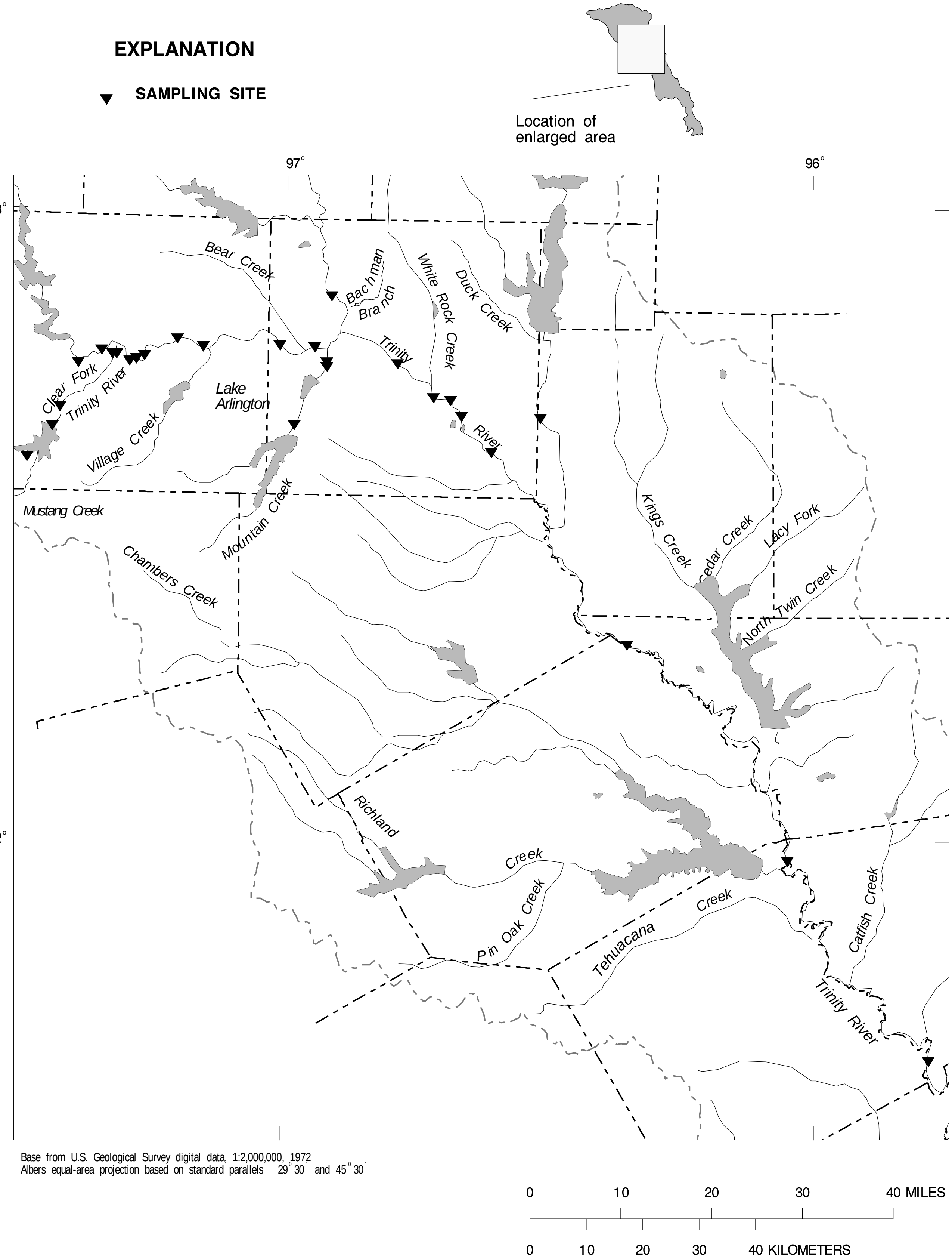
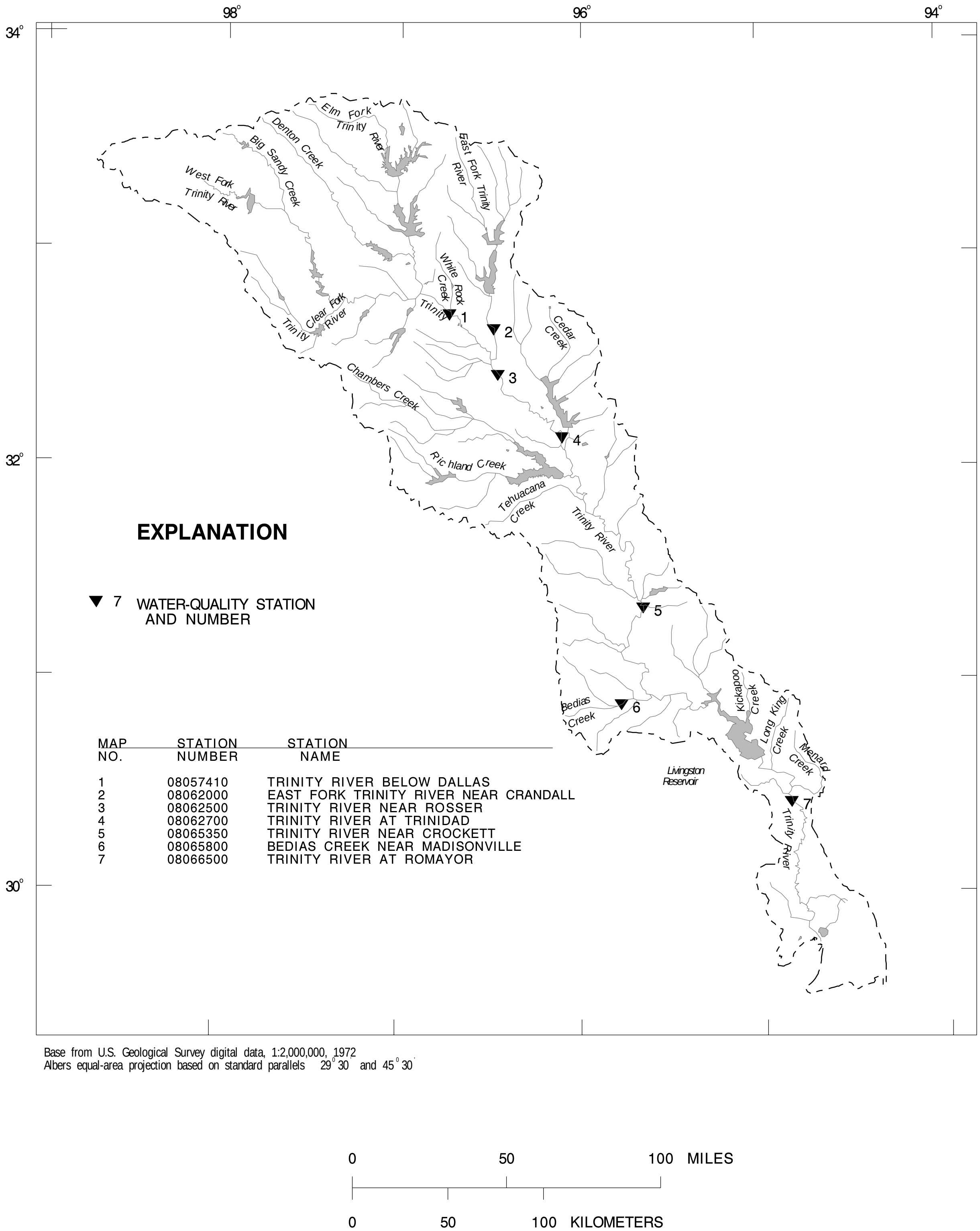


Figure 25. Location of U.S. Fish and Wildlife sampling sites for pesticide analyses.



MAP NO.	STATION NUMBER	STATION NAME
1	08057410	TRINITY RIVER BELOW DALLAS
2	08062000	EAST FORK TRINITY RIVER NEAR CRANDALL
3	08062500	TRINITY RIVER NEAR ROSSER
4	08062700	TRINITY RIVER AT TRINIDAD
5	08065350	TRINITY RIVER NEAR CROCKETT
6	08065800	BEDIAS CREEK NEAR MADISONVILLE
7	08066500	TRINITY RIVER AT ROMAYOR

Figure 26. Location of selected U.S. Geological Survey surface-water-quality stations.

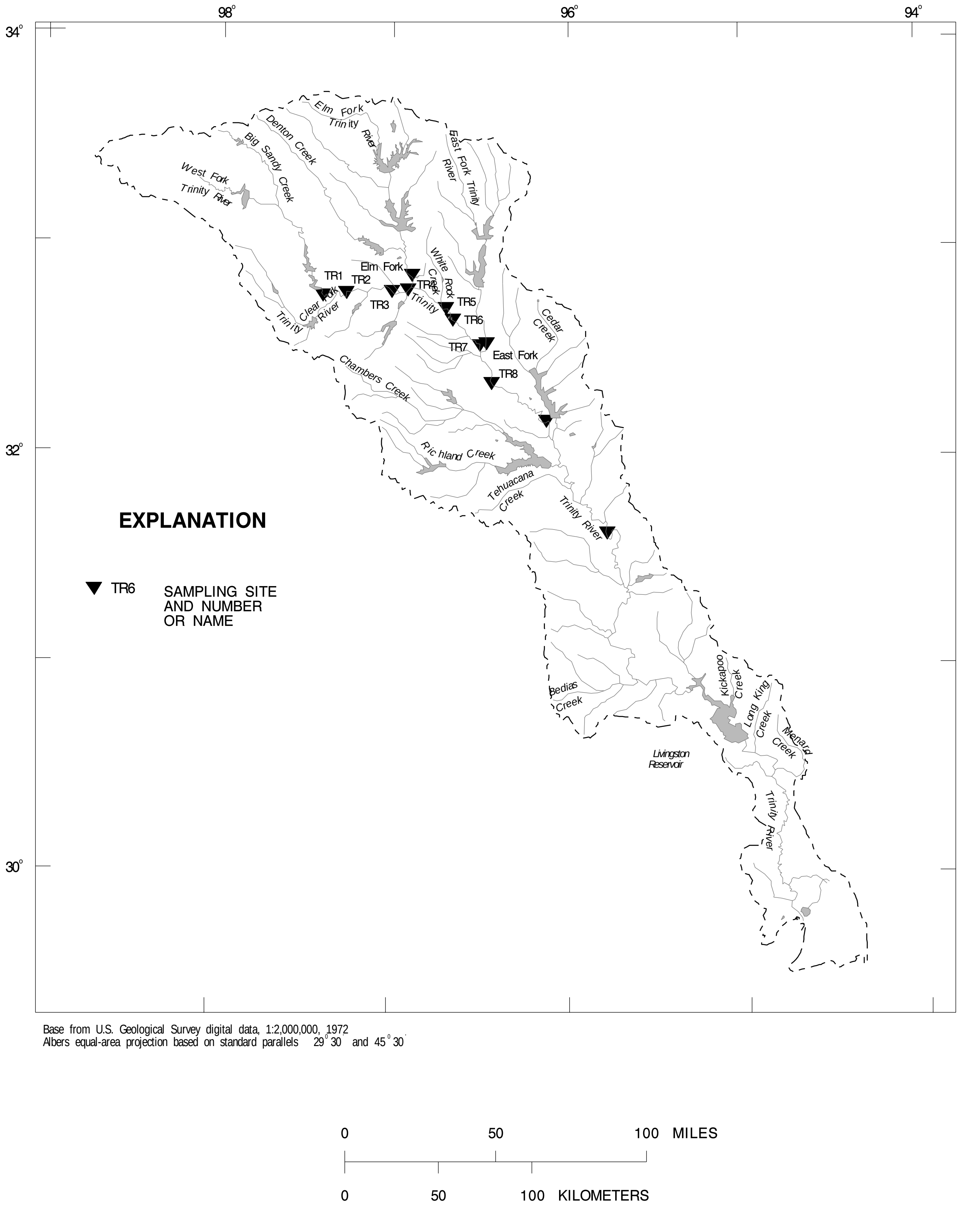


Figure 27. Location of University of North Texas and University of Texas at Dallas sampling sites for pesticide analyses.

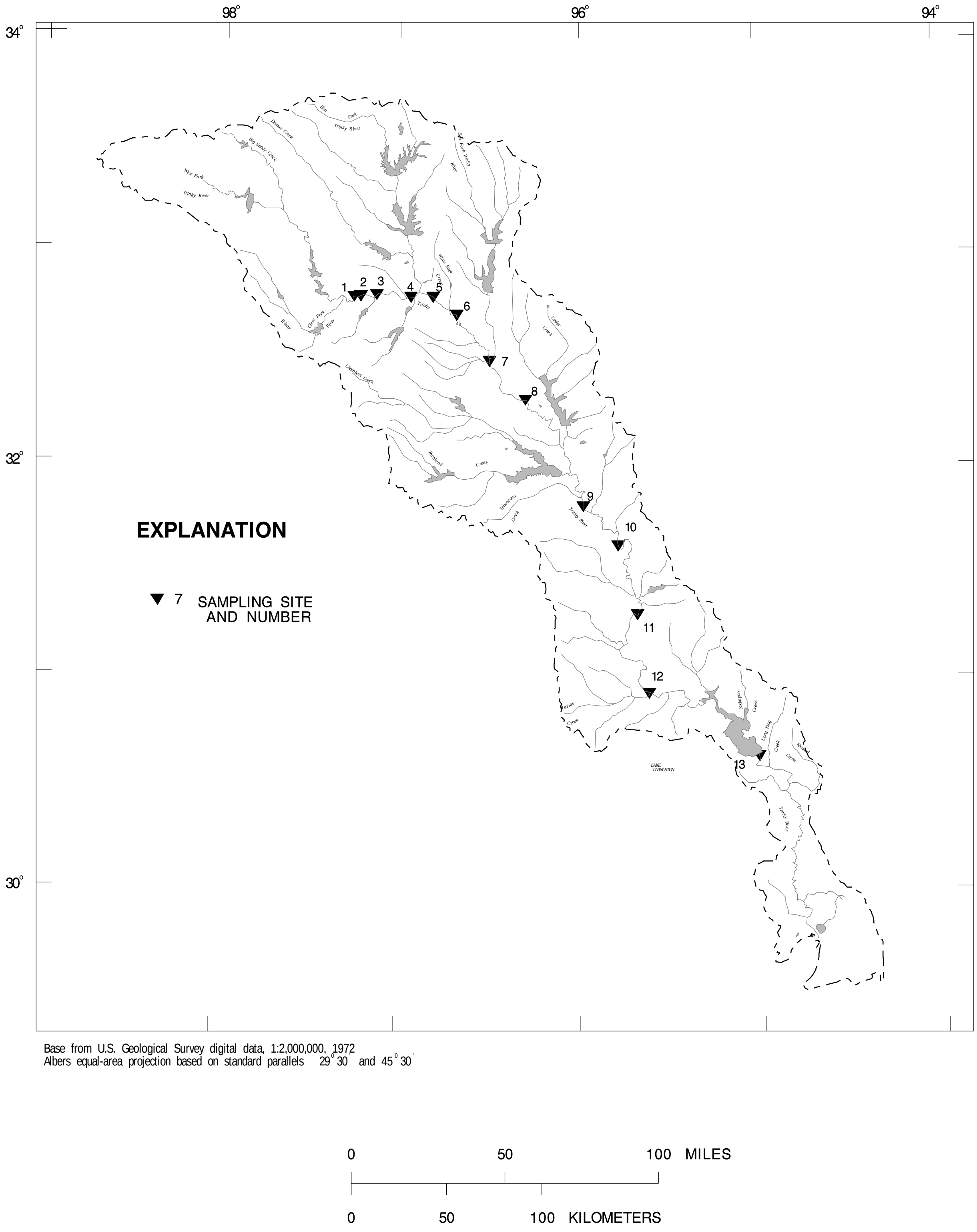


Figure 28. Locations of University of Texas at Arlington sampling sites for pesticide analyses.

involved primarily for its own specific purpose, it is difficult to apply a uniform method of review across all data sets. In general, each data set was reviewed to identify possible quality-assurance issues and, if possible, analyzed for spatial and temporal patterns or trends.

In some cases, the concentrations of pesticides are compared to applicable water-quality standards. These standards are given as reference points and to indicate which pesticide concentrations may be of concern. For concentrations in water, the standards include USEPA water-quality criteria for the protection of human health in the consumption of organisms (U.S. Environmental Protection Agency, 1992a), water-quality criteria for the protection of aquatic organisms (for both acute and chronic exposures) (U.S. Environmental Protection Agency, 1991a), and the Maximum Contaminant Level (MCL) for drinking water regulations (U.S. Environmental Protection Agency, 1990, 1991b). For concentrations in bed sediment, fewer standards are available for comparison. The USEPA **(**1991c**)** draft of sediment-quality criteria for the protection of benthic organisms is given. For fish tissues, the U.S. Food and Drug Administration (USFDA) **(**1992) action level for contaminant residue in fish tissue (used in interstate commerce regulations) is given. Also given for fish fillet data (Kleinsasser and Linam, 1989) is the USEPA fish tissue concentration associated with a 10^{-6} cancer risk (U.S. Environmental Protection Agency, Region IV, written commun. (toxic substance spreadsheet), 1993). For whole fish data, the National Academy of Sciences (1972) recommended maximum fish-tissue concentration for protection of fish-eating birds and mammals is given.

Detailed information on specific pesticides sampled for by each agency is given in table 4. Detection levels, if available, also are included along with the percent of samples with concentrations above the detection limit. Although the comparison of frequency of detections for a pesticide analyzed at different detection levels through time could be misleading, these numbers represent useful information which can, at a minimum, identify those areas where additional sampling may be appropriate. To describe the overall occurrence and distribution of pesticides in the study area, analyses from different agencies were combined, but caution is necessary in interpreting the results because of the varying detection levels and sampling designs.

Trends in concentrations of pesticides over time can be identified given sufficiently detailed data sets. Although data in table 4 indicates a large number of samples were analyzed for several pesticides, using trends criteria from Schertz (1990) as a guide, only one site, U.S. Geological Survey station 08062500, Trinity River near Rosser, had the recommended distribution of data for a statistically valid trend test on a period of 10 years or more. Trend tests were not attempted for other stations because of limitations of the data. Sampling frequency was greater during the late 1960’s and early 1970’s than in the later part of the data-collection period.

Table 5 shows a summary of percent detections of major pesticides in water, bed sediment, and tissue, based on data from all agencies (city of Arlington data was included only for 2,4–D and 2,4–TP), and total percent detects by pesticide class. As a class, the organochlorines were detected in 20 percent of the total 2,909 analyses from water, 13 percent of the total 5,060 analyses from bed sediment, and 31 percent of the total 981 tissue analyses. Organophosphates were detected in 24 percent of 1,119 water analyses, and 2 percent of 818 bed-sediment analyses. No tissue analyses were available. Chlorophenoxy pesticides were detected in 56 percent of the 769 water analysis and 35 percent of 252 bed-sediment analyses. The chlorophenoxy pesticides were detected in a higher percentage of analyses than either the organochlorines or the organophosphates probably because of their high solubility in water and extensive use in both agricultural and urban areas. Samples were collected by all agencies at a total of 155 surface-water sites and 121 ground-water sites.

A comparison of the frequencies of detection of selected pesticides across major river basins in Texas provides a regional overview useful to contrast pesticide occurrence in samples from the study area with pesticide occurrence in samples collected statewide. Dick (1982) reported a

Table 5. Summary of percent detections of selected organochlorine, organophosphate, and chlorophenoxy pesticides analyzed at surface-water sites in the study unit during the period 1968–88

[Data from sampling agencies listed in table 4. ---, no samples]

Pesticide	Percent detections in samples analyzed		
	Water	Bed sediment	Tissue
Organochlorine			
Aldrin	16	7	10
Chlordane	7	34	68
DDD	5	8	14
DDE	4	8	48
DDT	33	15	10
Dieldrin	49	30	54
Endrin	4	7	0
Heptachlor Epoxide	7	7	12
Lindane	47	15	9
Methoxychlor	6	0	---
Toxaphene	0	1	---
All organochlorine pesticides	20	13	31
Organophosphate			
Diazinon	59	6	---
Ethion	1	0	---
Malathion	30	0	---
Methyl Parathion	2	0	---
Parathion	3	1	---
All organophosphate pesticides	24	2	---
Chlorophenoxy			
2,4–D	62	47	---
2,4,5–T	48	4	---
All chlorophenoxy pesticides	56	35	---

summary of samples collected at U.S. Geological Survey surface-water-quality stations distributed throughout the State of Texas, from October 1973 to December 1977. Percentages of detects were calculated from this summary and contrasted with percentages for all agency samples, which are shown in table 5. These data (statewide percentages shown in parentheses below) indicate that, except for chlordane, pesticides were more frequently detected in samples from Trinity River Basin sites than from other surface-water sites in the State. Of the organochlorine pesticides, dieldrin was detected most frequently, in 49 (16) percent of all water samples, and detected in bed sediment at 30 (39) percent. Chlordane, detected in 7 (9) percent of water samples was also detected in bed sediment at 34 (38) percent and in tissue samples at 68 percent. Lindane was detected in 48 (9) percent of water samples and 14 (2) percent of bed sediment. Diazinon was detected most among the organophosphates, in 59 (35) percent of all water samples and in 6 (0) percent of bed-sediment samples.

City of Arlington

Minimum detection limits were not available for several of the pesticides in the city of Arlington data. This caused some concern about using concentrations or percent detections for analysis of this data set. The data indicate 100 percent detections for several pesticides. For those with less-than-100 percent detects, the concentrations for the detected values are often significantly lower than the given minimum detection limit. No detailed analysis was attempted on these data; however, 2,4–D was detected in 74 percent of 273 samples taken during a 10-year period. None of the values exceeded the USEPA MCL of 0.07 mg/L for drinking water (U.S. Environmental Protection Agency, 1992a) and only three exceeded the National Academy of Sciences Suggested No Adverse Response Level (SNARL) of 0.003 mg/L (National Research Council, 1977). Herbicide 2,4,5–TP also was detected in 59 percent of 265 samples during the same period. Detection levels were available for 2,4–D and 2,4,5–TP and are listed in table 4.

Dallas Water Utilities

During a storm on February 11, 1977, which resulted in a mean rainfall of 1.9 in. at 18 sites within the city of Dallas and 1.6 in. in the surrounding area of Dallas County, city personnel collected samples of runoff contributed from an urban area of 724 mi^2. The sampling took place at 17 sites including six at levee pump stations and pressure sewers which convey street runoff from the storm sewer system to the Trinity River (URS12, 13, 14, 15, 16, 17 on fig. 22). Hydrographs were available for six of the other sites (URS1, 5, 7, 8, 9, 10 on fig. 22) which represent the West Fork Trinity, the mainstem of the Trinity River, and three other tributaries (Bachman Creek, Turtle Creek, and White Rock Creek). As shown in table 4, several pesticides were detected in 50 percent or more of their respective samples. Organochlorines in this group included: (1) alpha-BHC at 92 percent, (2) DDT at 50 percent, (3) dieldrin at 87 percent, (4) heptachlor at 55 percent, and (5) lindane at 90 percent. The only organophosphate with a high percentage of detections was diazinon at 56 percent. The chlorophenoxy herbicide 2,4–D was detected in 56 percent of the analyses.

The availability of a storm hydrograph detailing flow conditions during the storm sampling provides an opportunity to examine pesticide concentrations relative to stream-discharge flow through time. Figure 29 shows the concentration of diazinon plotted on the storm hydrograph for sampling site URS5 on the Trinity River at South Loop 12 (corresponds to U.S. Geological Survey station 08057410 on fig. 26). Diazinon concentrations are shown to increase as discharge increases during the storm, and to peak approximately 24 hours before peak discharge occurred. This peak in concentration ahead of peak in discharge (observed for most constituents sampled) illustrates a typical storm-water runoff event. That is, the erosion of fine sediment and washing of other constituents accumulated during dry periods from the land surface or storm drains during the first appreciable runoff from the watershed. Concentrations then decrease with time as available sediment and other readily erodible materials are depleted from the contributing drainage area. Due to the lack of information on the minimum detection limits for analyses, only the distribution of the concentrations in relation to each other was considered. Without the minimum detection limit the lower values are questionable.

Texas Parks and Wildlife Department

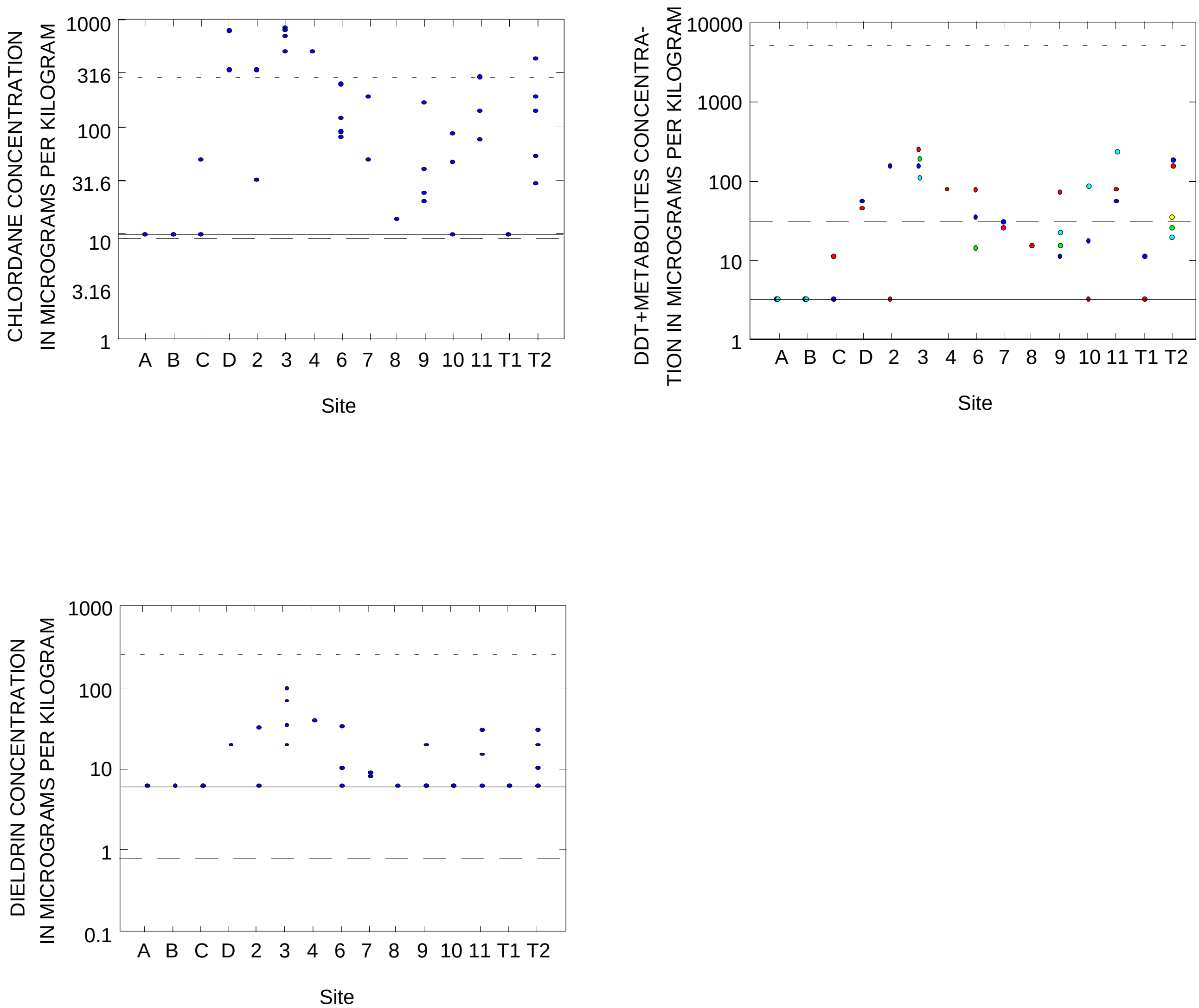
Figure 30 shows the concentrations of chlordane, dieldrin, and DDT plus its metabolites in 41 fish tissue (fillet) samples collected at 15 sites in 1987 and 1988 (see fig. 23 for site locations). Results of this study (Kleinsasser and Linam, 1989) suggested that elevated chlordane levels in the Trinity River were related to urban or suburban runoff. Chlordane was below detection limits in

Figure 29. Stream discharge and diazinon concentrations for six samples during 1977 storm, site URS5, Dallas.

five samples from sites free of major urban runoff (sites A, B on fig. 23). Chlordane was detected in only one of three samples from the Trinity Park area in Fort Worth (site C on fig. 23) and the concentration (50 µg/kg) was below the USFDA action level of 300 µg/kg. However, concentrations in eight of nine samples from the next four sites downstream, which are within or adjacent to the urban centers of Fort Worth and Dallas, exceeded the USFDA action level. In addition, one sample from the East Fork Trinity River (site T1 on fig. 23), also in the urban area, exceeded the USFDA action level (Kleinsasser and Linam, 1989). Concentrations were highest at site 3 (fig. 23), which is upstream of U.S. Geological Survey water-quality station 08057410, Trinity River below Dallas, Texas, where some of the highest concentrations of chlordane and dieldrin were found in bed sediment. Although only chlordane values exceeded USFDA action levels, concentrations of all three of these organochlorines exceeded USEPA fish tissue concentrations associated with a 10^{-6} cancer risk. USEPA cancer risk values are based on estimates of total daily intake for humans and represent a carcinogenic potency factor for the pesticide.

Texas Water Commission

Table 4 shows that, in 1990, ground-water samples were taken from 18 wells for analysis of the major organochlorine, organophosphate, and chlorophenoxy pesticides and that none of these pesticides were detected (Arthur and Ambrose, 1992). In 1990, arsenic was sampled for at 100 wells (including the above 18). The wells ranged in depth from 50 to 2670 ft, with an average depth of 764 ft. 28 were domestic or stockyard wells, 64 were municipal wells, 4 were industrial or commercial wells, and 4 were irrigation wells. No



EXPLANATION

Minimum Detection Limit

Action Level for contaminant residue in edible fish (U. S. Food and Drug Administration, 1992)

Fish tissue concentration associated with 10E-06 cancer risk (U. S. Environmental Protection Agency, 1992b)

Figure 30. Concentrations of organochlorine pesticides in fish tissue from Texas Parks and Wildlife sampling sites during 1987–88.

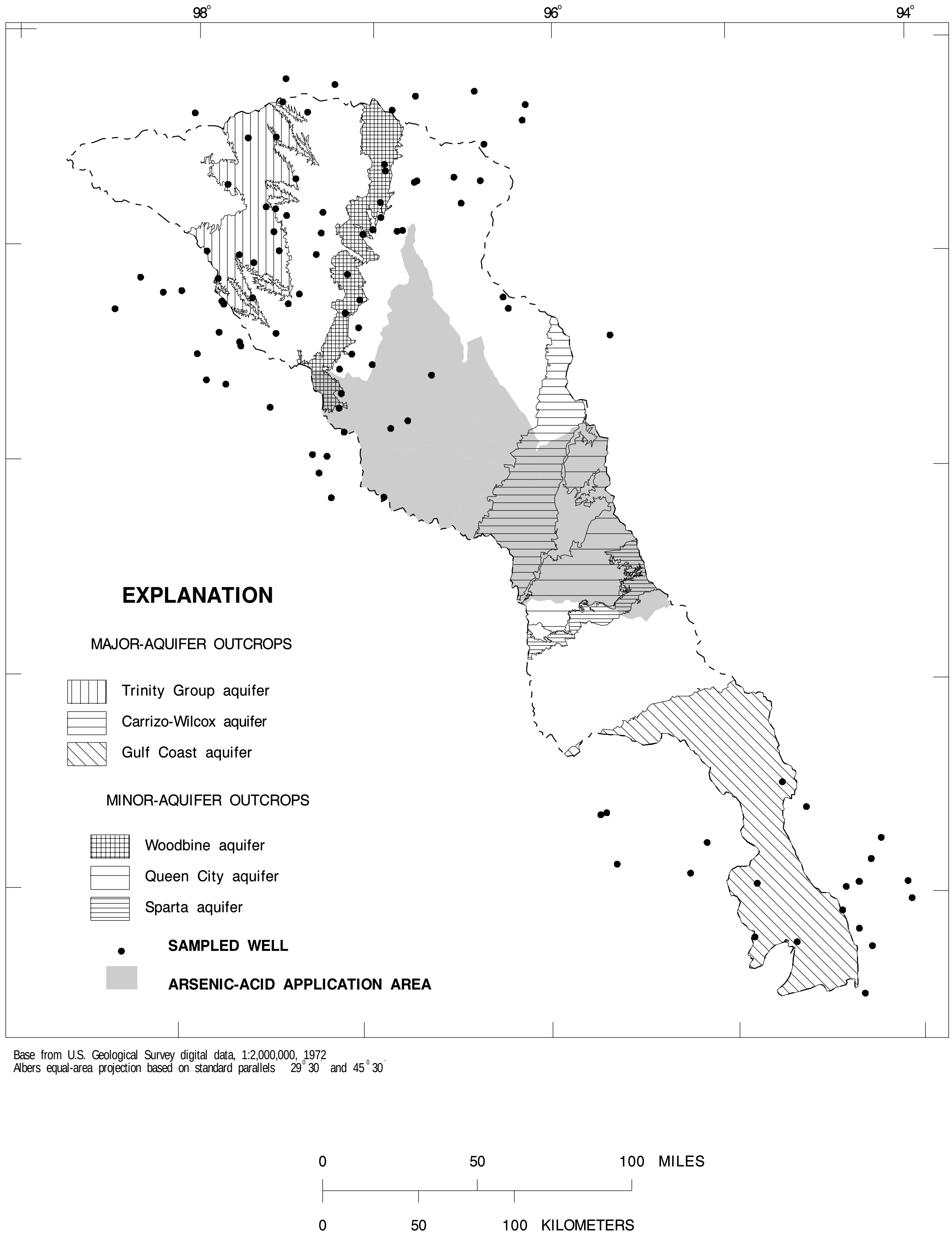


Figure 31. Location of Texas Water Commission sampled wells, aquifer outcrops, and areas in the study unit where arsenic acid was applied during 1988–90.

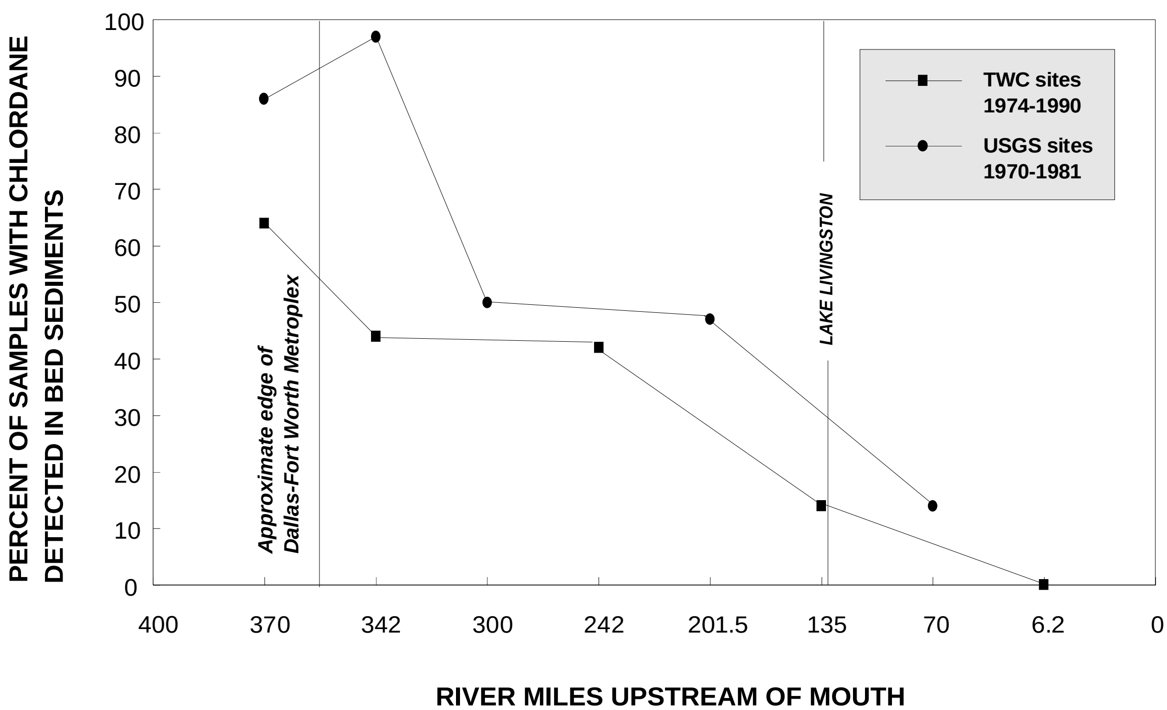


Figure 32. Detections of chlordane in bed sediment at selected U.S. Geological Survey and Texas Water Commission sites during two time periods.

arsenic was detected in any of the samples. Figure 31 shows the location of the sampled wells, aquifer outcrops areas, and areas where arsenic acid was applied on cotton during 1987–90.

Surface-water samples were taken for the analysis of herbicides 2,4–D, and 2,4,5–T during several periods and under various detection limits (table 4). Overall, 2,4–D was detected in 35 percent of 62 samples and 2,4,5–T was detected in 33 percent of 58 samples.

Organochlorine pesticides were sampled from bed sediment during several sampling periods between 1974 and 1991. Chlordane was detected in 25 percent of the 183 samples, DDE in 14 percent of 186 samples, lindane in 9 percent of 183 samples, and dieldrin in 9 percent of 187 samples. Figure 32 shows a comparison of the chlordane detects in these samples and chlordane detects in samples taken at U.S. Geological Survey surface-water-quality stations along the mainstem Trinity River, during overlapping time periods. The graph shows the typical geographic distribution of organochlorine pesticides in bed sediment in the study area, that is, the largest percentage of detects occurring just below the Dallas-Fort Worth urban area and smaller percentages as the distance downstream increases.

Organophosphate pesticides were sampled from bed sediment from 1978 to 1991. Diazinon was detected in 7 percent of the 183 samples and parathion in 1 percent of 185 samples. 2,4–D was detected in 6 percent of the 88 samples and 2,4,5–T in 5 percent of 88 bed samples collected.

During 1983–89, tissue samples were collected and analyzed for DDT and dieldrin. Twenty-eight percent of the 18 samples contained DDT and 89 percent contained dieldrin. These numbers can be contrasted with Texas Parks and Wildlife Department samples for DDT (34 percent) and dieldrin (46 percent) taken during 1987–1988, and with U.S. Fish and Wildlife Service samples for

DDT (0 percent) and dieldrin (77 percent), taken during 1985.

United States Fish and Wildlife Service

Irwin (1988) found elevated levels of chlordane and organochlorine pesticides other than DDT and its metabolites in fish and wildlife in the Trinity River Basin. Residues of most contaminants were higher in tissues of six species of fish and turtles at the site downstream of Dallas than those collected at a reference site on Mustang Creek (tributary to Lake Benbrook) upstream of known urban contaminant sources. Four tissues with more than 5 percent lipid content were chosen as gradient-monitoring indicators of organic contaminants body burdens. The tissues used were whole-body spiny, softshell turtles (*Trionyx spiniferus*); fatty tissues from red-eared slider turtles (*Trachemys scripta*); and whole-body samples of smallmouth buffalo fish (*Ictiobus bubalus*); and carp (*Cyprinus carpio*). A Wilcoxon signed rank statistical test for paired samples showed that concentrations were higher at the impacted site than the reference site 36 out of 37 times (97 percent) when organic contaminants were detected at either site. Mosquitofish (*Gambusia affinis*) were used in this study as an indicator to study body burdens of contaminants related to river mile.

Significant spatial correlations ($p<0.02$) were found between the chlordane components oxychlordane, trans-nonachlor, and cis-nonachlor as well as the combination of chlordane components and dieldrin in mosquitofish tissue and river mile (Irwin, 1988). Sites having little or no residential runoff were associated with lower chlordane concentrations in tissue, and sites with residential runoff were associated with higher concentrations in tissue, which indicates residential areas are significant sources of chlordane in urban runoff. Dieldrin concentrations in mosquitofish showed a tendency to increase from upstream of Fort Worth to the area downstream of Dallas. In both this study of fish and wildlife and a Texas Water Quality Board (Bohmfalk, 1977) study of sediments, dieldrin was one of the most frequently encountered organochlorine pesticides at all Trinity River sites and was detected at most Dallas-Fort Worth sites (Bohmfalk, 1977). Lindane was detected only at sites downstream of sewage treatment plants. This was noteworthy even though the compound was detected only in 7 of 64 samples (11 percent). Because it is continually degraded and eliminated from the body, lindane’s presence in fish suggests the possibility of a continued source despite its few remaining legal uses. The author recommended that an additional study be undertaken to determine if sediment and fish and wildlife of Livingston Reservoir are serving as the ultimate repository for chlordane and dieldrin, as well as various metals.

United States Geological Survey

Organophosphate pesticides were analyzed in surface-water samples collected in the study area beginning in 1970 and ending in 1981. Figure 33 shows the percent of samples with organophosphate pesticides detected in unfiltered water. The downstream ordering of the stations shows a similar spatial pattern as was described for organochlorine pesticides in the Texas Water Commission section of this report. That is, the highest percentage of detects occurring in upstream reaches, which drain urban areas, with smaller percentages as distance downstream from the urban area increases.

This spatial trend is evident in surface-water samples and also in bed-sediment samples. Figure 34 shows boxplots of concentrations of organochlorine pesticides in water, and figure 35 shows concentrations in bed sediment for four main-stem stations. Both figures show that the largest pesticide concentrations, as well as the greatest number of detections above the detection limit, occurred at the upstream stations closest to the urban areas.

Organochlorine pesticides are known to be very persistent in the environment. Figures 36 and 37 show, however, that although they were consistently detected, concentrations of some organochlorine pesticides in water or in bed sediment were decreasing through time at the seven U.S. Geological Survey stations (fig. 26), as

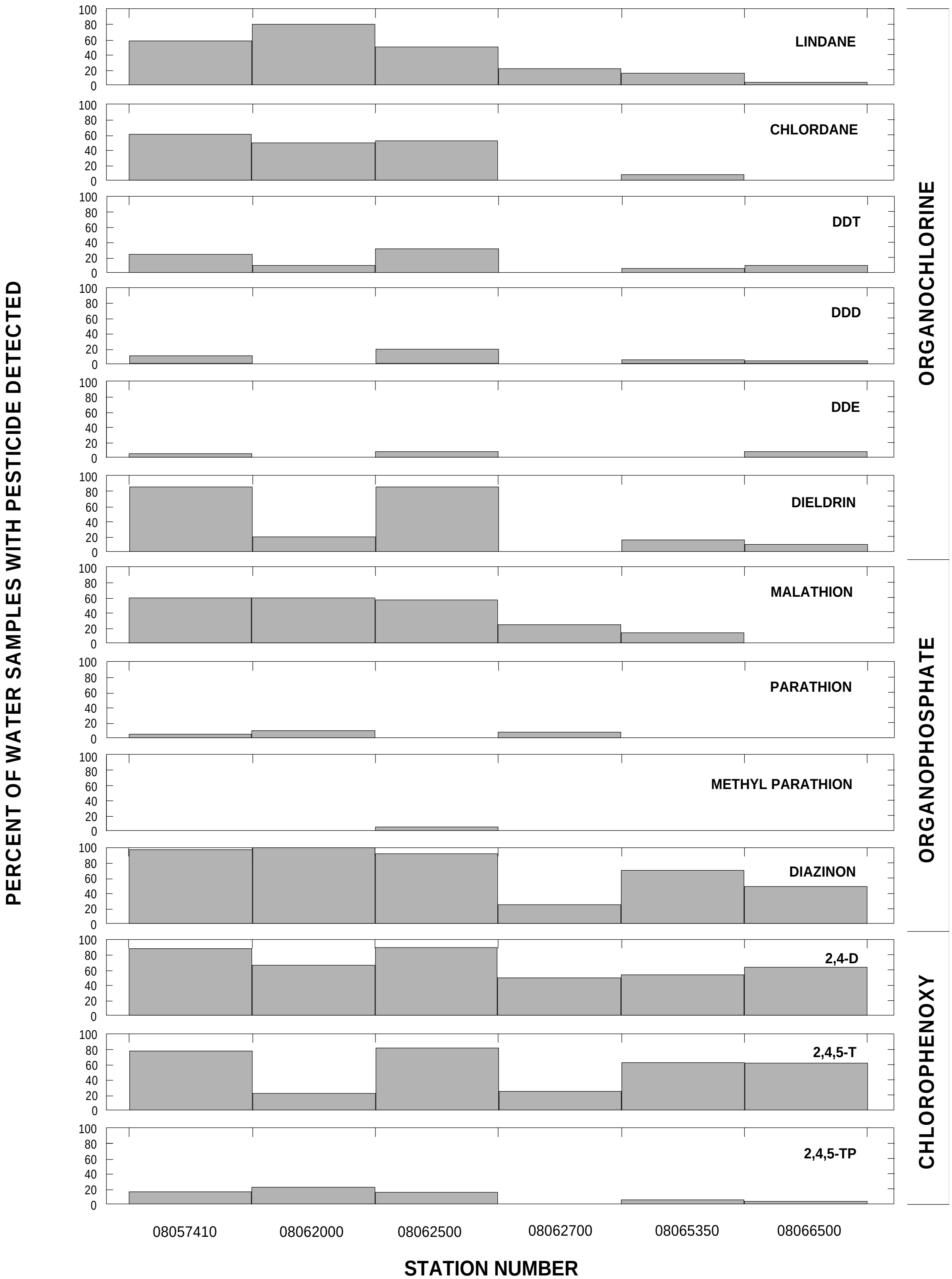


Figure 33. Percent of water samples with pesticides detected at U.S. Geological Survey surface-water-quality stations.

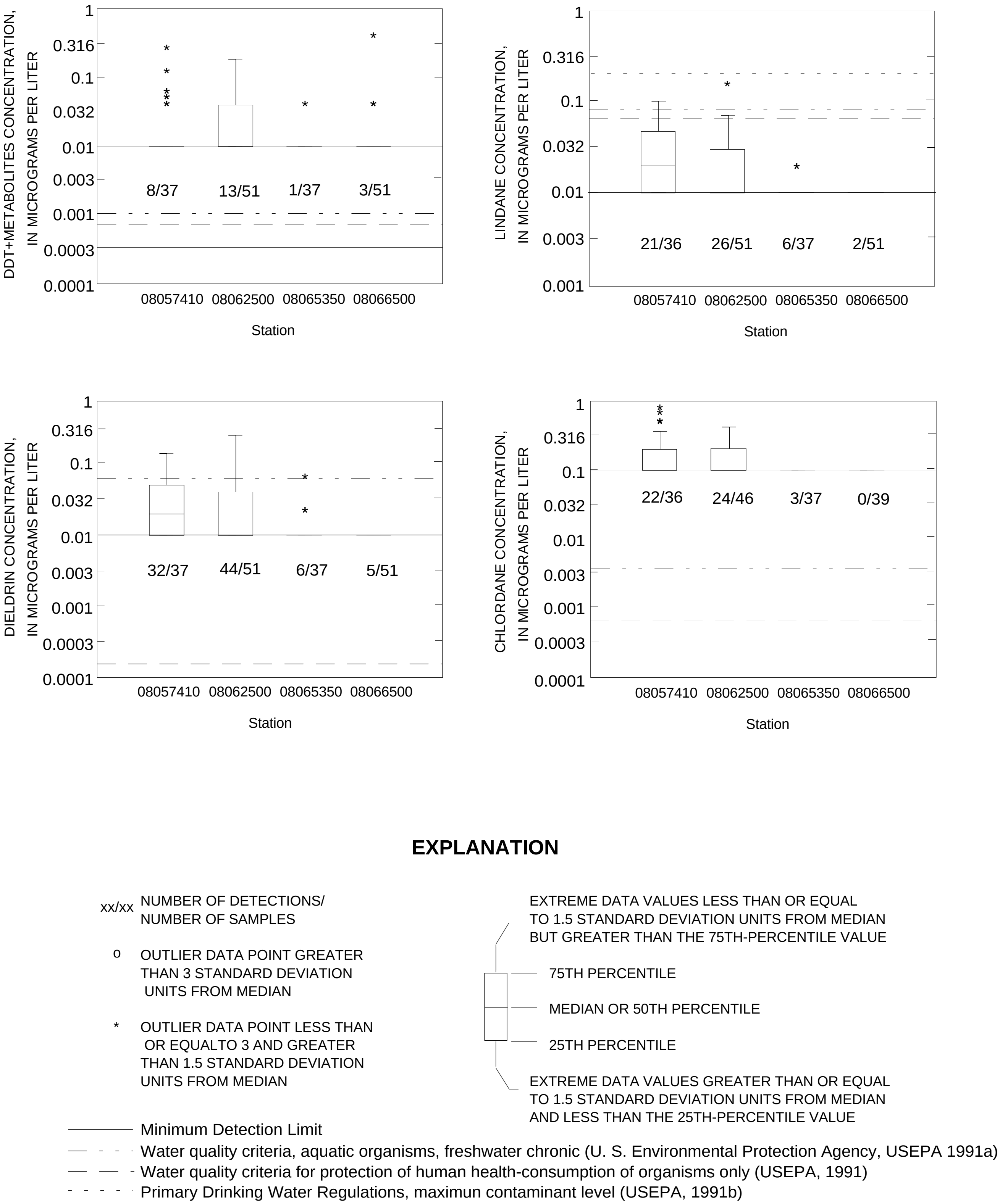


Figure 34. Concentrations of organochlorine pesticides in water at selected U.S. Geological Survey surface-water-quality stations during 1968–89.

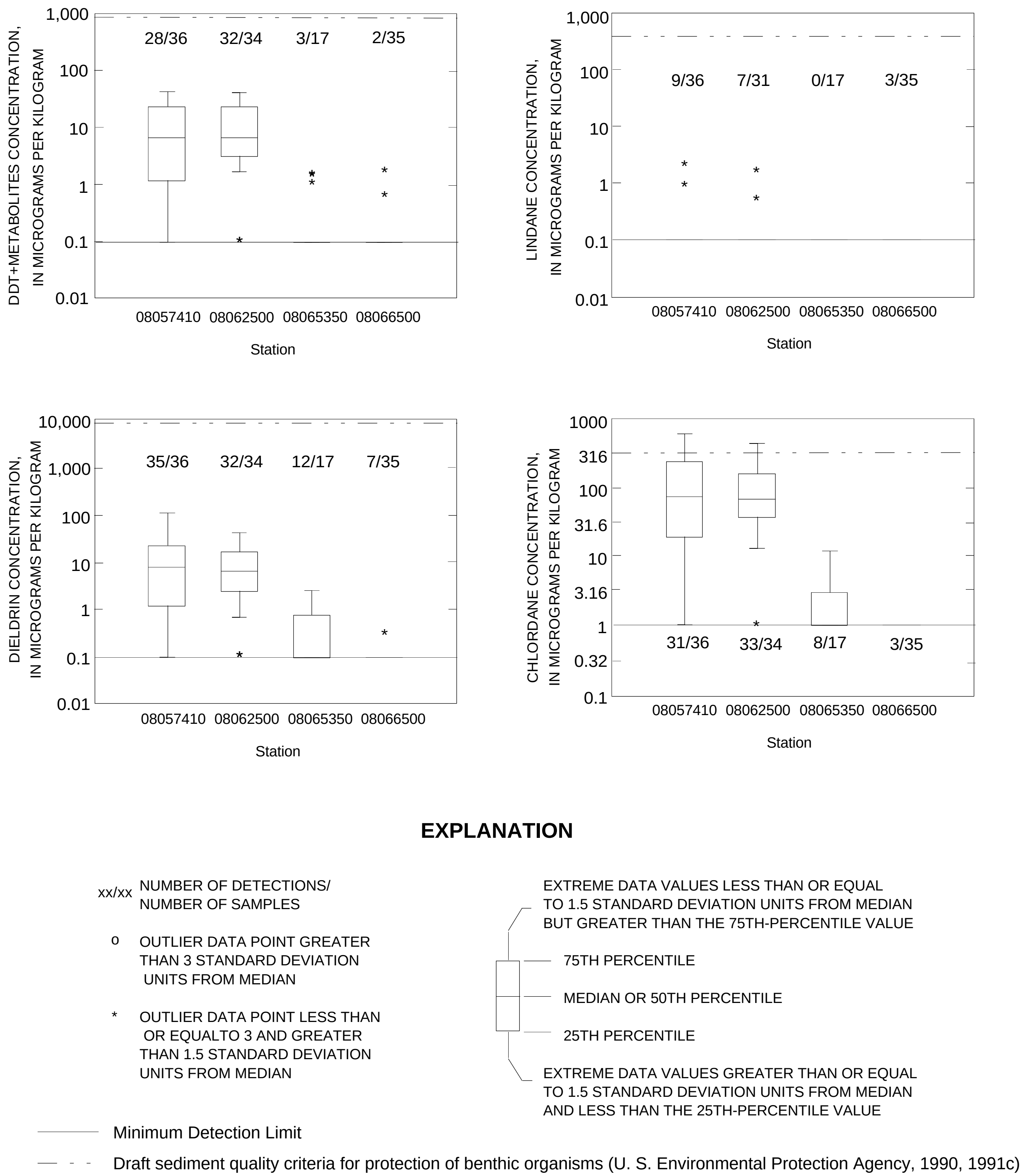


Figure 35. Concentrations of organochlorine pesticides in bed sediment at selected U.S. Geological Survey surface-water-quality stations during 1968–89.

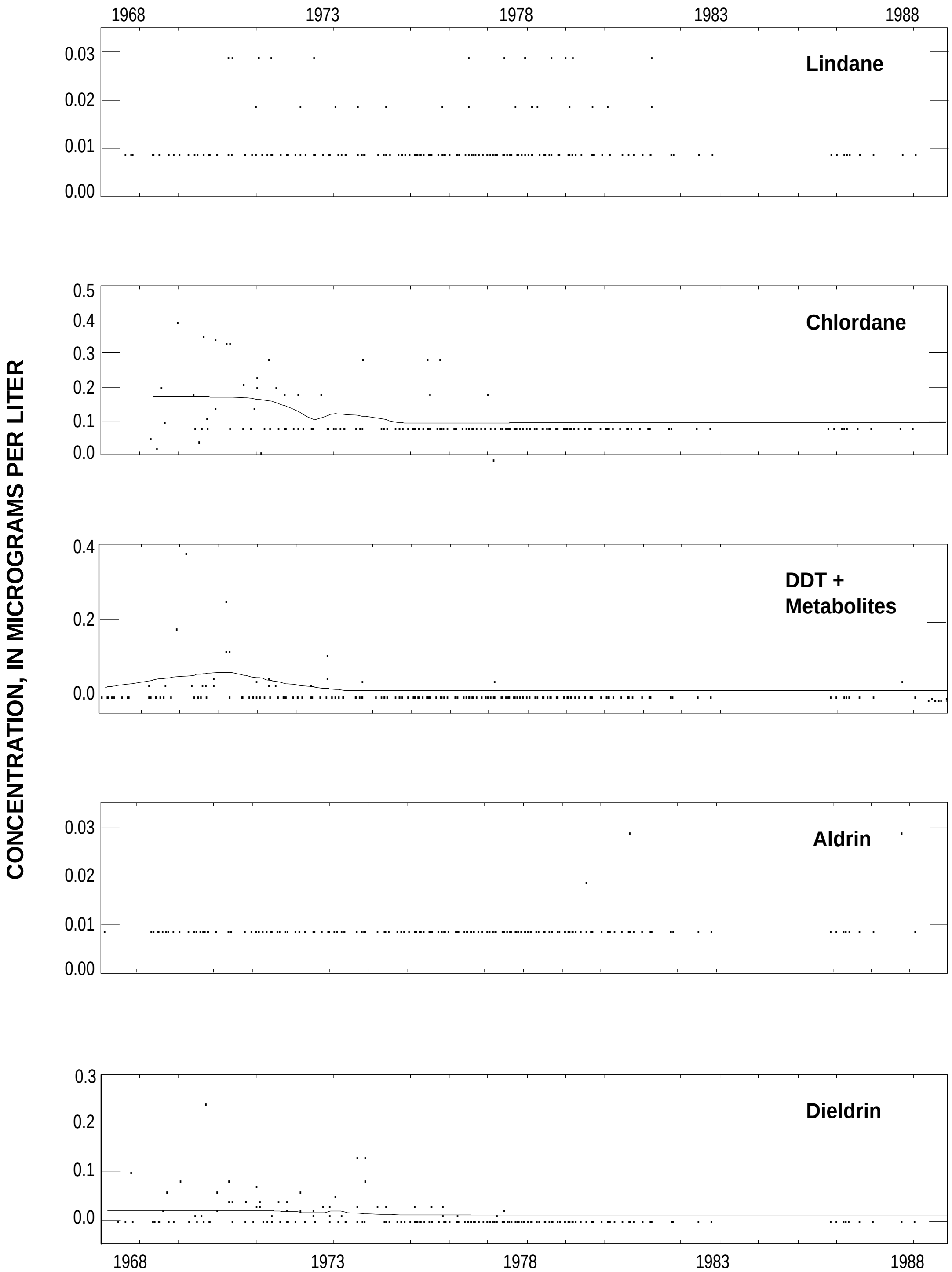


Figure 36. Concentrations of organochlorine pesticides in water at selected U.S. Geological Survey surface-water-quality stations during 1968–89.

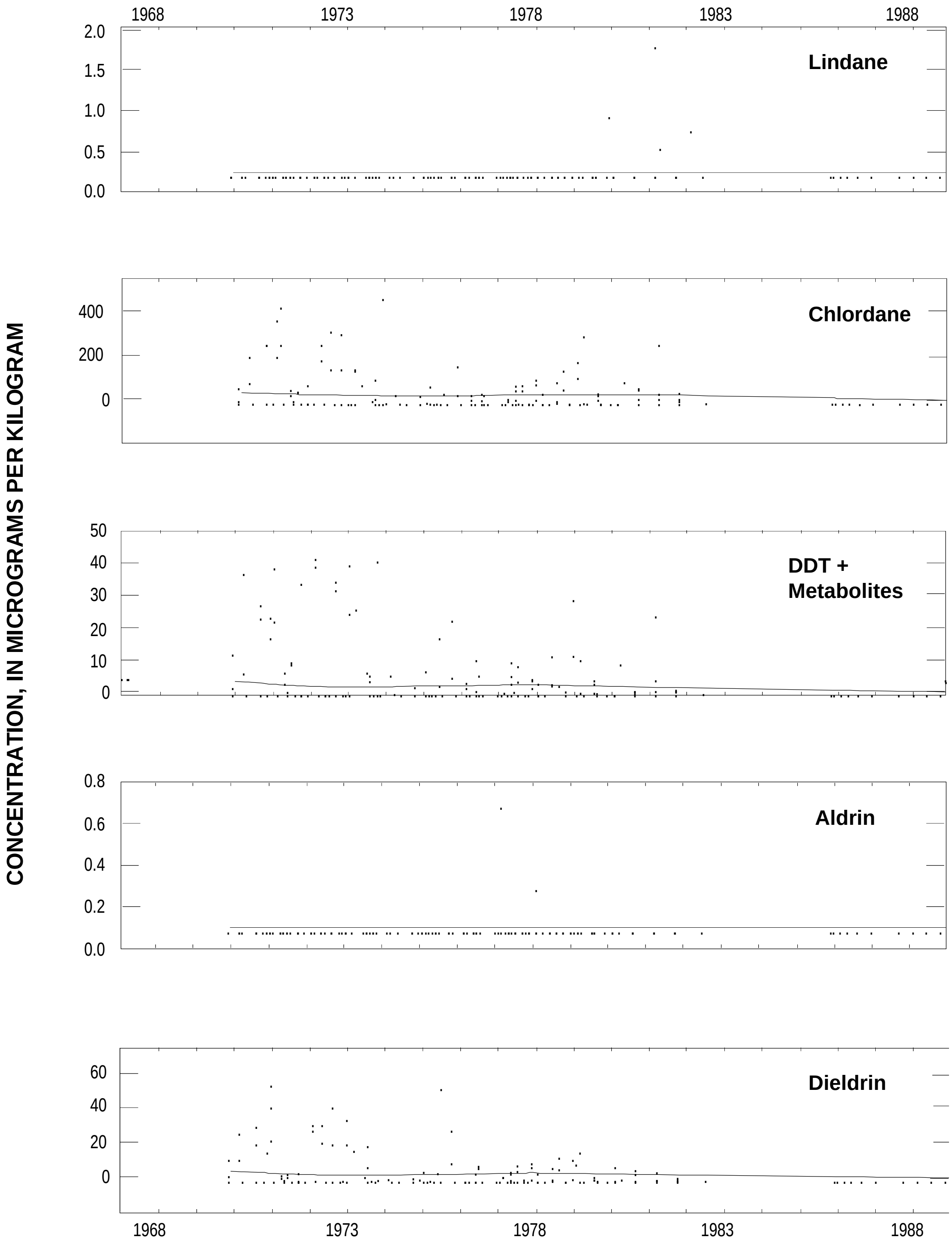


Figure 37. Concentrations of organochlorine pesticides in bed sediment at selected U.S. Geological Survey surface-water-quality stations during 1968–89.

indicated by the LOWESS or LOcally WEighted Scatterplot Smoothing curve (Helsel and Hirsch, 1992, p. 210–217). The LOWESS curve is a locally weighted moving average which, in this case, shows temporal trends in concentration. No-detect values influence the LOWESS smooth line, but the overall downward trend may be observed for some of the organochlorine pesticides. A Seasonal Kendall trend test (Helsel and Hirsch, 1992) was applied to chlordane data from station 08062500, Trinity River near Rosser (selected due to availability of sufficient data). The Seasonal Kendall test accounts for seasonality by computing the Mann-Kendall test on m number of seasons separately, and then combines results (Helsel and Hirsh, 1992). No trend (p=0.065) was detected in chlordane concentrations for the period 1969–79.

Malathion and diazinon were observed in samples from most stations. Malathion originates in both agricultural and urban areas, where it is sprayed to control aphids and other sucking insects and mosquitoes around streams or wetlands. Diazinon is used extensively throughout the study area in agriculture and urban areas and is the most persistent of the organophosphate pesticides. Figure 38 shows that the median concentrations of diazinon was relatively high in upper reaches of the basin as indicated at station 08057410, and decreased downstream. Figure 39 shows the trends in organophosphate concentrations for the period 1968–88.

Chlorophenoxy pesticides were detected in samples taken throughout the basin. Sampling began at six of the seven sites in 1968 and concluded in 1981. Additional sampling was conducted at one station during 1985–88. Figure 40 shows concentrations of 2,4–D, 2,4,5–T, and 2,4,5–TP at selected main-stem stations. Figure 41 shows concentrations of these chlorophenoxy pesticides with a LOWESS smooth line. A seasonal Kendall trend test applied to data from station 08062500, Trinity River near Rosser, indicated a downward trend of -0.0155 (µg/L)/year (p=0.067) in 2,4–D for the period 1969–79.

University of North Texas

Figures, 42, 43, and 44 show concentrations of pesticides in water, bed sediment, and fish tissues at University of North Texas sampling sites (Dickson and others, 1989). This data set offers the opportunity to compare samples in three media collected at the same sites during the same period. The concentrations of organochlorine pesticides generally show the expected distribution (due to their relative insolubility in water) of the highest concentrations in fish tissue, followed by bed sediment, and then water. The low solubility and high persistence of these compounds result in their eventual concentration in fish tissues (Dick, 1982). An exception to this is lindane which is considerably more soluble than the other organochlorines. Lindane was detected in only two tissue samples.

Chlordane concentrations exceeded standards in both water and fish tissue (fig. 42, 44) at three sites. Four out of the five sites where water standards were exceeded were within the Dallas-Fort Worth urban area. Interestingly, chlordane, DDT + metabolites, and dieldrin were detected in tissues at stations where there were no detections of these compounds in water or bed sediment. The low solubility and high persistence of these compounds result in their eventual concentration in fish tissues (Dick, 1982), so the source of the tissue concentrations is in question.

University of Texas at Arlington

Samples were analyzed for six pesticides (table 4). Chlordane was detected in only 46 percent of bed samples and was not detected in any of 13 water samples. All five other pesticides were detected in at least 77 percent of water and 80 percent of bed samples. This study (Qasim and others, 1980) found pesticide concentrations highest in water samples obtained from the central reach of the river, which is located downstream from the urban area. No chlordane was detected in water or bed-sediment samples collected where the dominant land use activity was cropland, pasture, and forest. Pesticide concentrations in bed-sediment samples were highest in the upper reach

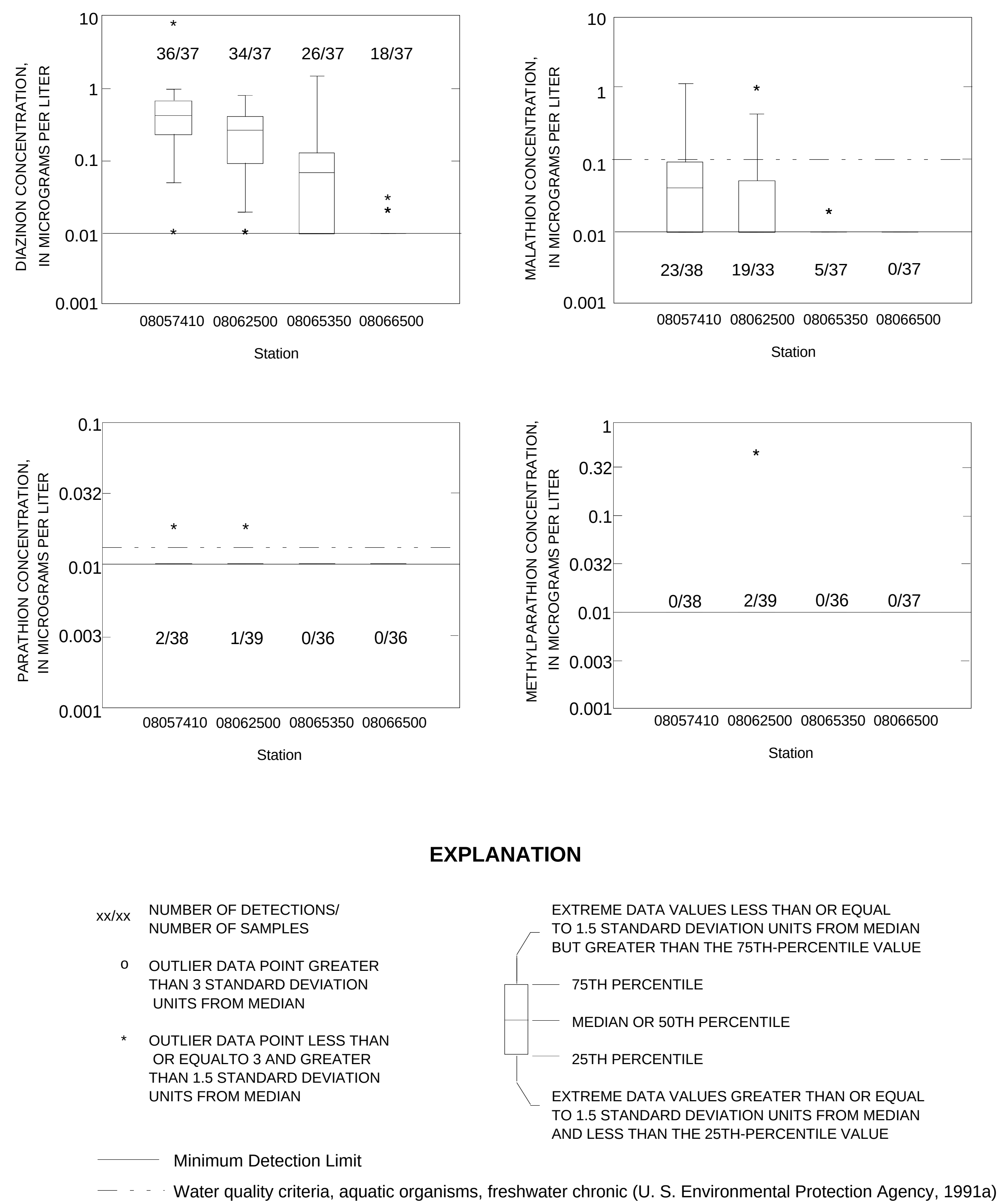


Figure 38. Concentrations of organophosphate pesticides in water at selected U.S. Geological Survey surface-water-quality stations during 1968–89.

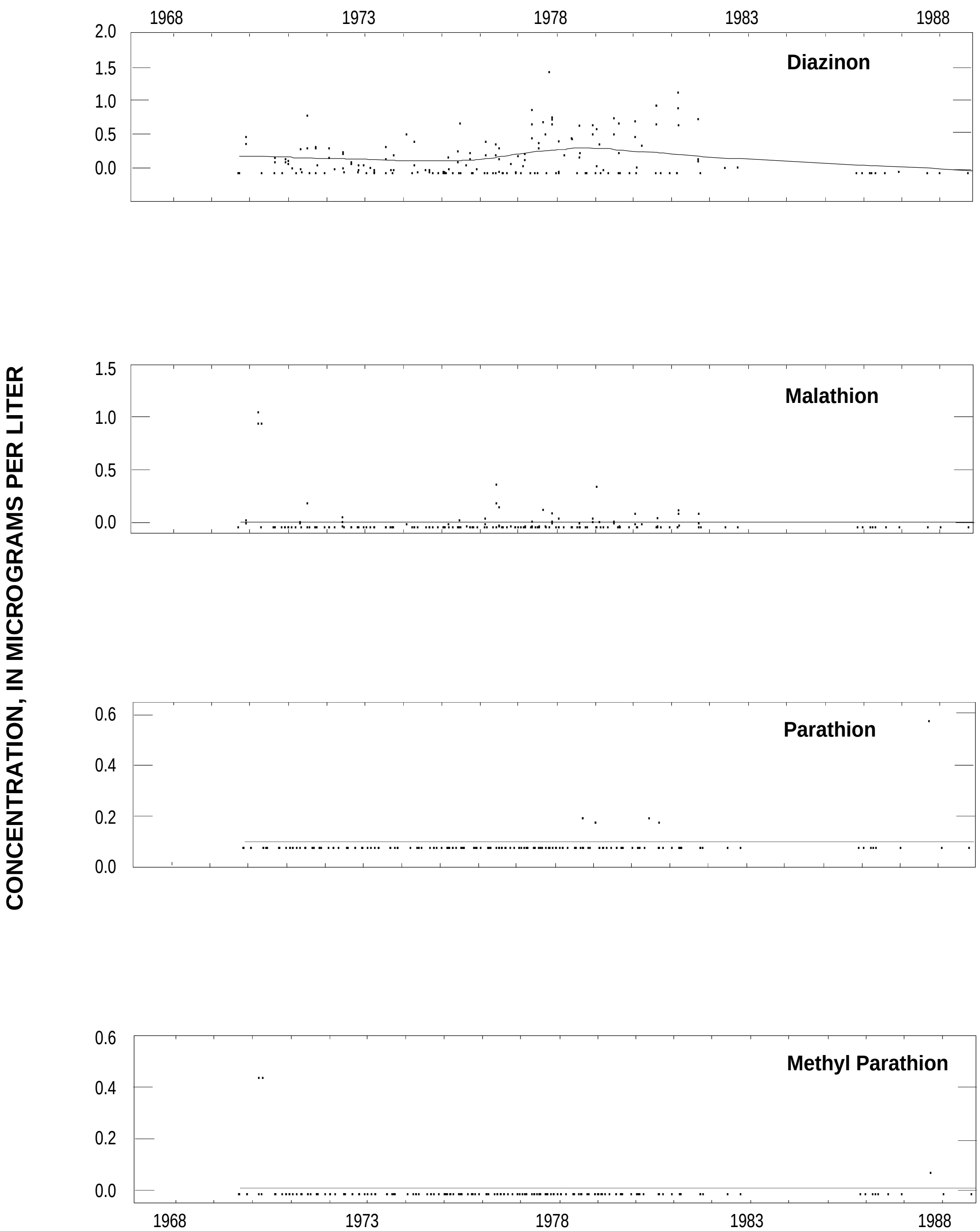


Figure 39. Concentrations of organophosphate pesticides in water at selected U.S. Geological Survey surface-water-quality stations during 1968–89.

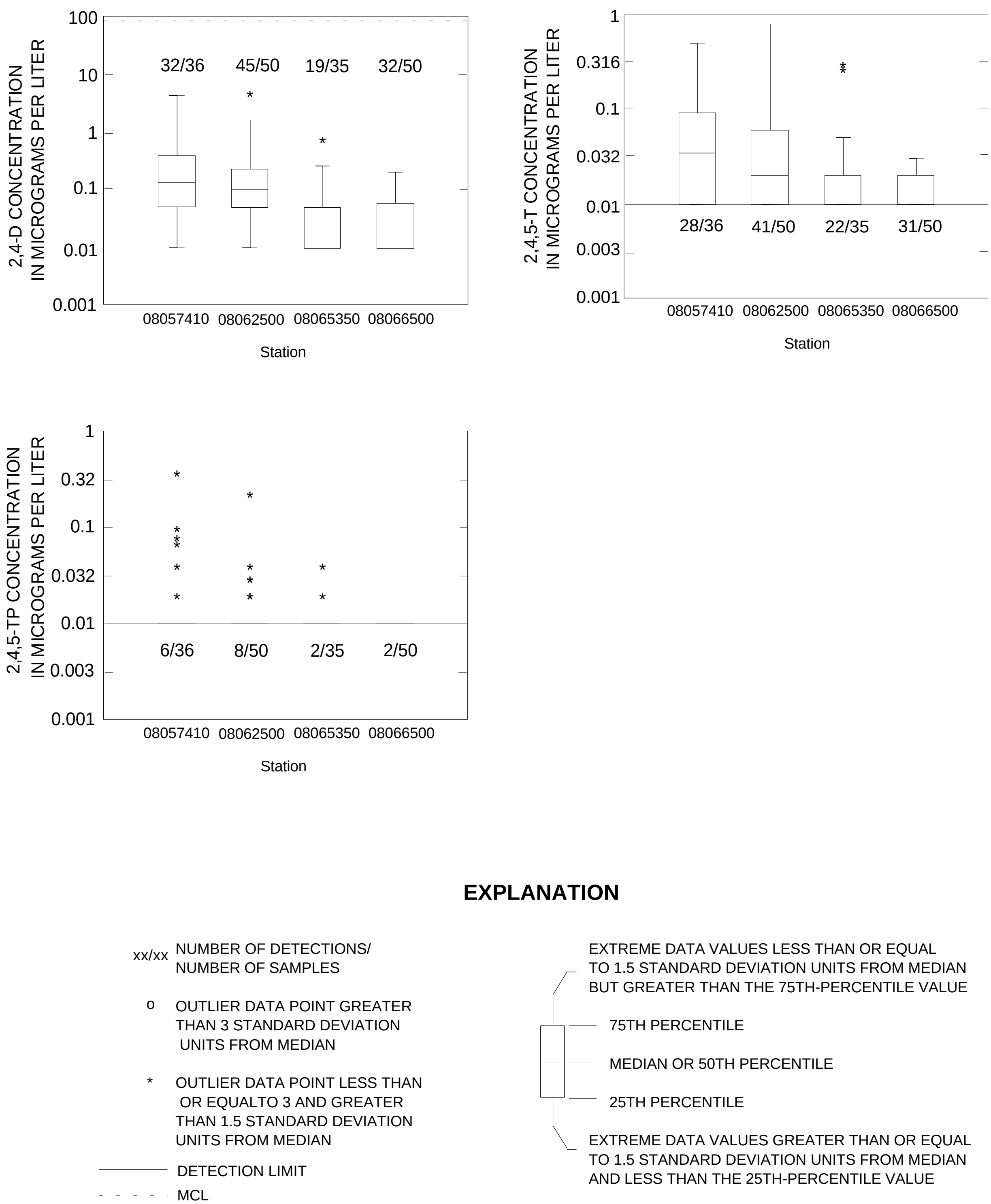


Figure 40. Concentrations of chlorophenoxy pesticides in water at selected U.S. Geological Survey surface-water-quality stations during 1968–89.

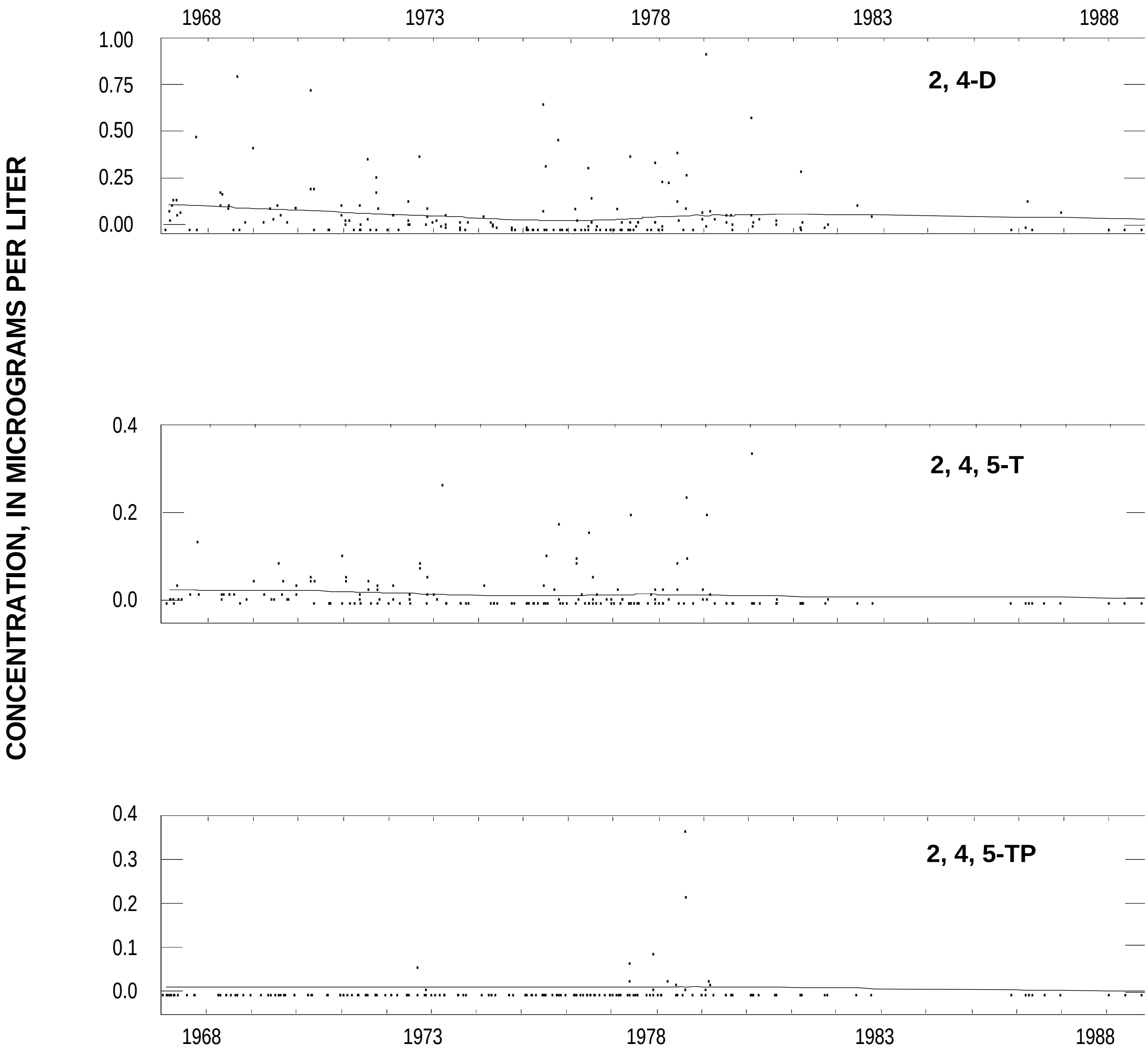
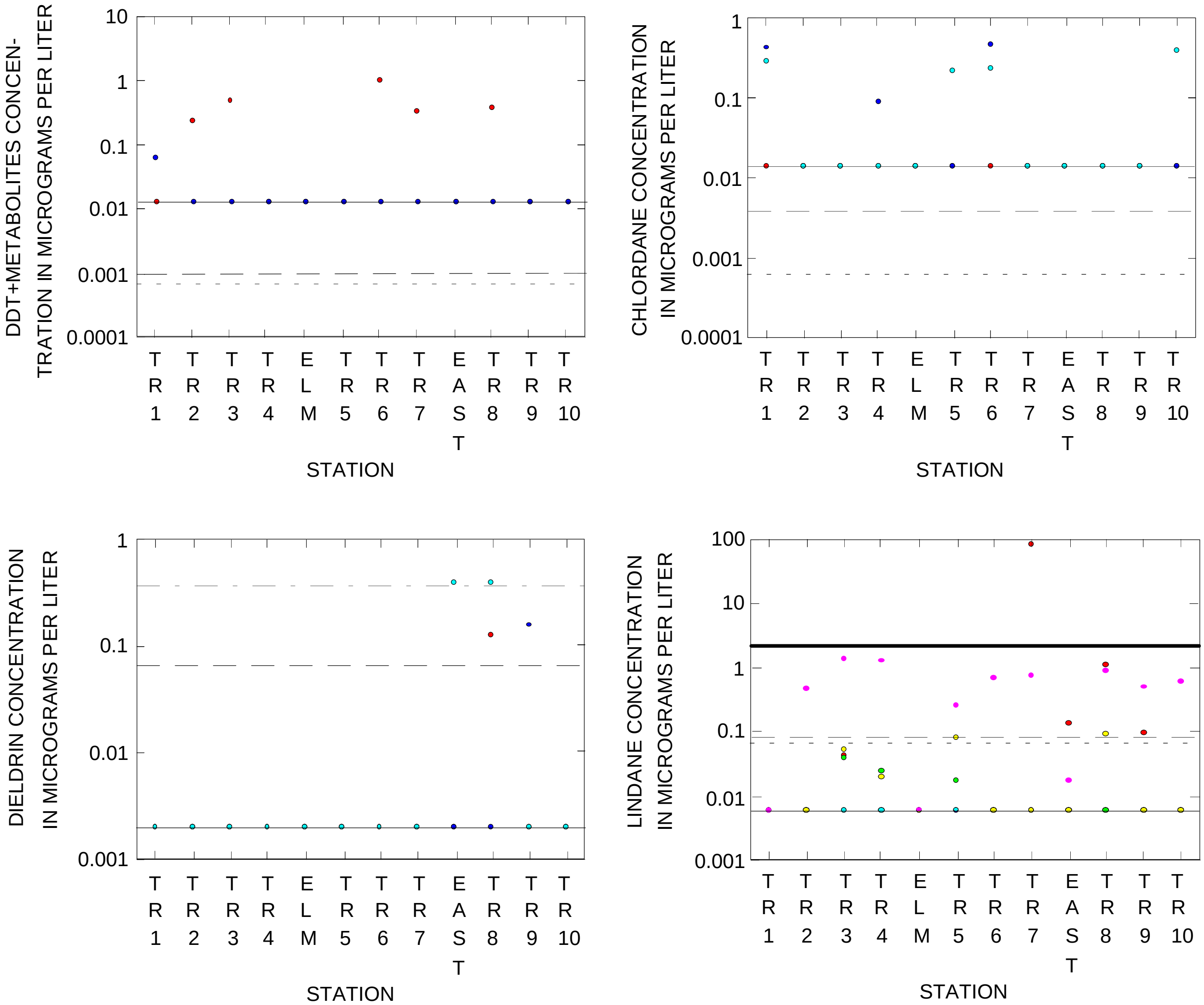


Figure 41. Concentrations of chlorophenoxy pesticides in water at selected U.S. Geological Survey surface-water-quality stations during 1968–89.



EXPLANATION

Minimum Detection Limit

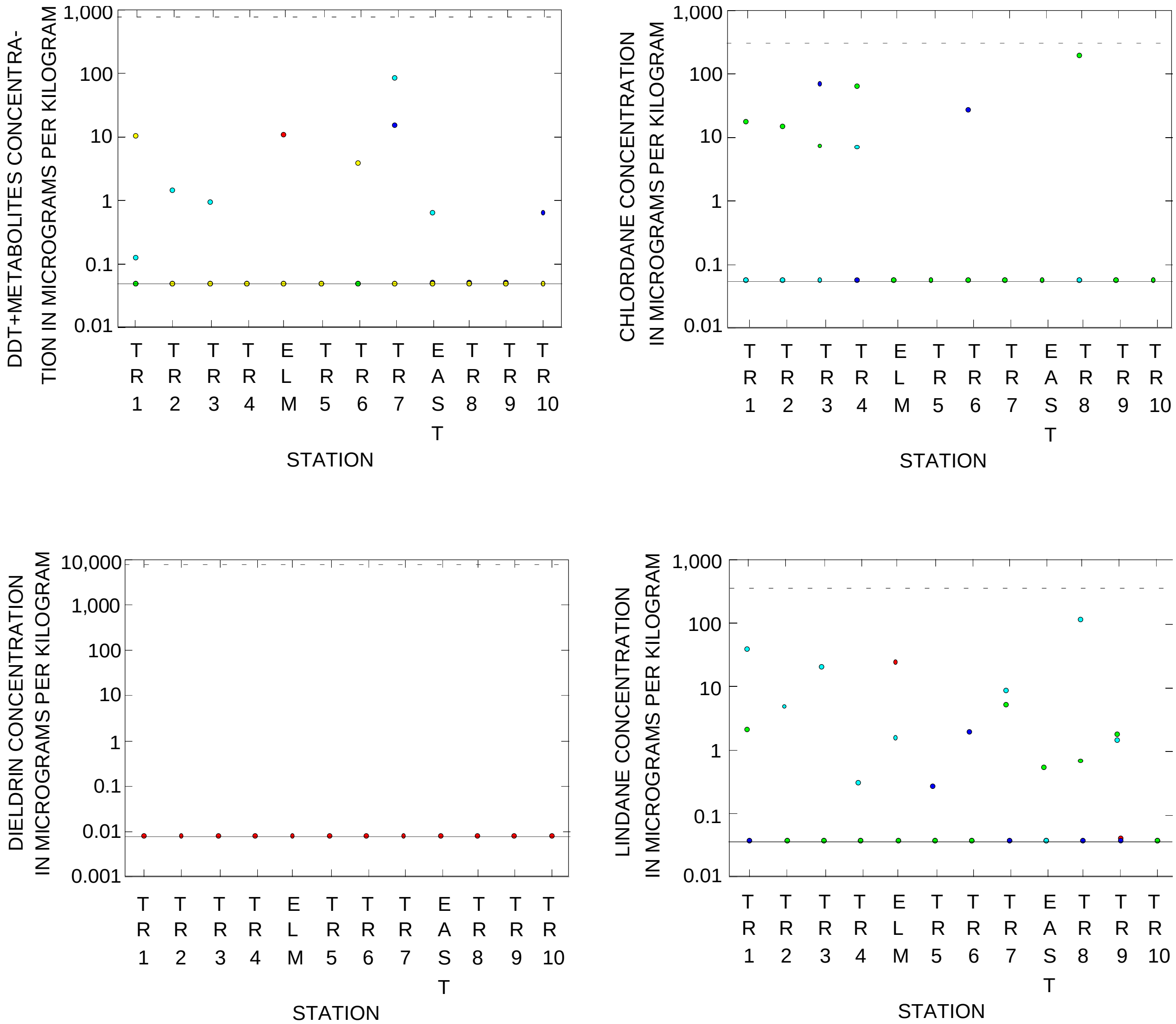
Water quality criteria for protection of human health-consumption of organisms only (U. S. Environmental Protection Agency, USEPA, 1991)

Water quality criteria, aquatic organisms, freshwater chronic (USEPA, 1991a)

Water quality criteria, aquatic organisms, freshwater acute (USEPA, 1991a)

Water quality criteria, aquatic organisms, freshwater acute. Primary drinking water regulations, maximum contaminant level (USEPA, 1991b)

Figure 42. Concentrations of organochlorine pesticides detected in water at University of North Texas and University of Texas at Dallas pesticide sampling sites during 1987–88.

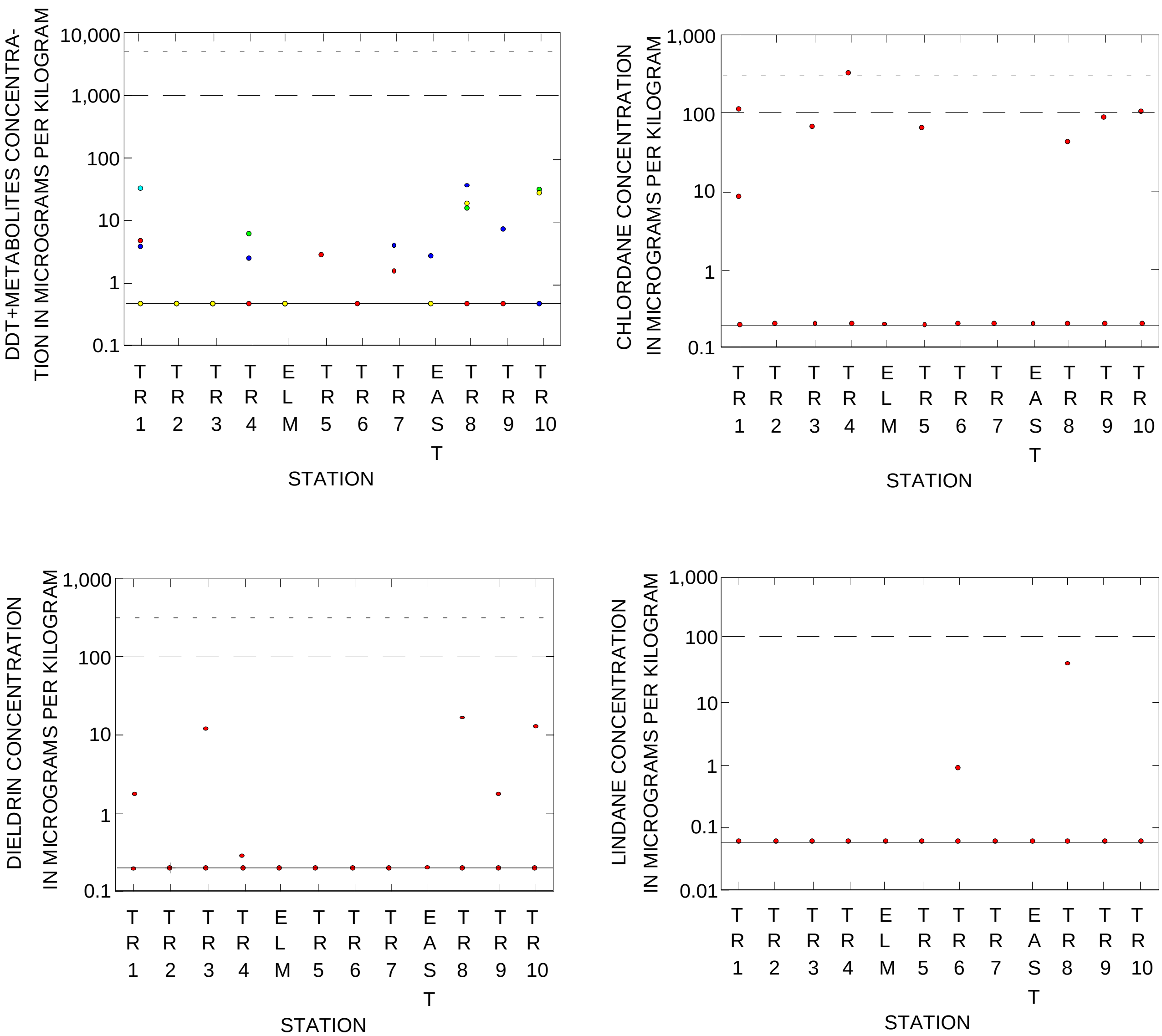


EXPLANATION

Minimum Detection Limit

Draft sediment quality criteria for protection of benthic organisms (U. S. Environmental Protection Agency, 1990, 1991c)

Figure 43. Concentrations of organochlorine pesticides in bed sediment at University of North Texas and University of Texas at Dallas sampling sites during 1987–88.



EXPLANATION

Minimum Detection Limit

Action Level for contaminant residue in edible fish (U. S. Food and Drug Administration, 1992)

National Academy of Sciences (1972) recommended maximum fish tissue concentration

Figure 44. Concentrations of organochlorine pesticides in fish tissue at University of North Texas and University of Texas at Dallas sampling sites during 1987–88.

of the river (in and downstream from the urban area). This finding is in agreement with the general geographic distribution already discussed.

Correlation of Pesticide Detections with Environmental Factors

One of the long-term goals of the NAWQA program involves the establishment of cause and effect relations between environmental factors and water quality. Meeting this goal will require detailed, recent, large-scale ancillary information about land-use practices, data on the types, amounts, and timing of applications of pesticides within each contributing watershed above a sampling site, and additionally, data on physical factors such as soils, vegetation, and slope. Some preliminary statistical testing of relations between pesticide detections and environmental factors was done for this study using available information on applied amounts of various pesticides. Ancillary information was available from various sources on the general use of pesticides sampled—for example, the fact that chlordane was primarily used around buildings in urban areas to control termites. This knowledge, when combined with the land-use and land-cover classification developed for the study area, was used to explore any relations between percent of land use or land cover and the percent of samples with various pesticides detected. As described earlier, the land-use and land-cover classification for the study area is generally representative of what occurred during 1973–81, however, any individual area's classification is subject to normal random errors, or subject to variations relating to the evolving nature of land use over time. At best, significant correlations of pesticide occurrence with land use or land cover indicate overall regional trends and serve as starting points for more detailed analysis once new data have been collected.

Rank correlation testing, using Spearman's rank correlation (rho) was conducted to determine the existence of any statistically significant geographic patterns or trends in pesticides detected and the ILRU, or the land-use class. Spearman's rho, a nonparametric, statistical technique, is considered to be a measure of the increasing (or decreasing) monotonic relation (not necessarily linear) between two variables. This test is equivalent to its parametric counterpart, Pearson's *r*, which measures the strength of the linear relationship between two variables (Iman and Conover, 1983), but it is not subject to the influence of extreme values (outliers). The contributing drainage area to each U.S. Geological Survey surface-water-quality sampling site was determined and then overlaid on maps of ILRUs and land-use classification. The contribution of each ILRU and each land-use class, as a percent of the sampling site's contributing drainage area, then was determined. These percents of contribution (independent variable) then were ranked and correlated with ranked percents of the number of chlordane, dieldrin, DDT + metabolites diazinon, malathion, methyl parathion, 2,4–D, 2,4,5–T, and 2,4,5–TP (dependent variables) detected at each of seven U.S. Geological Survey water-quality stations in water and bed sediment.

Table 6 lists only significant rank correlations between the individual pesticides in both water and bed sediment with ILRU or land use. Rank correlations were derived for the ILRU as well as for the land-use and land-cover data, because although the land-use classification identifies those areas where pesticides may have been applied, the ILRU characterizes additional physical factors such as soil type, vegetation, and topography, which also influence the occurrence and distribution of pesticides in the study area. Additionally, because agricultural activities occur only in areas with physical conditions conducive to them, and because the ILRU is a classification based on many of those physical conditions, the ILRU provides an index of the "capability" of the land to support various activities, which is not time-dependent, as is land use and land cover. Correlations established between percent of pesticides detected and ILRU percentages in the watershed can be used to make inferences about watersheds without current land-use information.

There were statistically-significant correlations between detections in bed sediment and land-use or land-cover class. The correlation of urban land use with percent detections of chlordane in bed sediment samples supports the findings of Qasim

Table 6. Rank correlations of land use or land cover, or distance from stream mouth, with percent detections in samples collected at U.S. Geological Survey surface-water sampling sites (at 90-percent confidence level)

[do., ditto; ---, correlation not significant]

	Type of sample	Pesticide name					
		2,4–D	Chlordane	Diazinon	Dieldrin	Lindane	Malathion
Integrated land resource unit							
North Central Prairie	Water	---	0.82	---	0.81	---	---
Western Cross Timbers	do.	0.71	---	---	---	---	---
Eastern Cross Timbers	do.	---	0.71	---	0.78	---	---
Blackland Prairie	do.	---	-0.96	---	-1.00	---	---
Texas Claypan	do.	-0.84	---	---	---	---	---
Bottomlands	do.	-0.77	---	---	---	---	---
Land use or land cover							
Urban or built-up	Water	---	---	0.71	---	0.89	0.78
Agricultural	do.	---	---	---	---	---	-0.70
Rangeland	do.	---	---	0.71	---	0.89	0.78
Forest land or wetlands	do.	---	---	---	---	---	-0.72
Urban or built-up	Bed sediment	---	0.82	---	0.82	---	---
Agricultural	do.	---	-0.79	---	-0.75	---	---
Rangeland	do.	---	0.82	---	0.82	---	---
Forest land or wetlands	do.	---	-0.71	---	-0.75	---	---
Distance from stream mouth							
Distance	Water	---	---	---	---	1.00	0.97
Distance	Bed sediment	---	0.90	---	0.90	---	---

and others (1980) of little association between chlordane detects and the amount of agricultural or forest and wetland in the contributing drainage area. The percent of chlordane detects in water was significantly correlated with the percent of the North Central Prairie and Eastern Cross Timbers. The percent of water samples with chlordane detected increased as the percent of the contributing watershed classified as North Central Prairie or Eastern Cross Timbers increased, and decreased as the percent of Blackland Prairie increased. This was expected due to the presence of significant urban areas in the North Central Prairie and in the Eastern Cross Timbers. In addition, U.S. Fish and Wildlife Service sample data at the site located on the West Fork of the Trinity River (fig. 25) showed that 92 percent of fish-tissue samples contained chlordane, and 90 percent of bed-sediment samples at the Texas Water Commission sampling site on the West Fork Trinity River (fig. 24) also contained chlordane. The West Fork Trinity River is the main drainage network for the North Central Prairie and Eastern Cross Timbers regions (fig. 2, 5).

Those pesticides which are applied primarily in urban areas were found to be positively correlated with urban land use or with ILRUs that contain significant urban areas and negatively correlated with agricultural or forest land. The significant negative correlation between the ranked percent of the Blackland Prairie within the sampling sites' contributing area and ranked percent detects of chlordane probably is related to the history of the ILRU as an agricultural area with little urban development. Additionally, chlordane and dieldrin are negatively correlated with agricultural or forest and wetland classes of land use. This agrees with correlations discussed by other authors relating residential (included in the urban class) land use and detections of chlordane (Irwin, 1988). The percent of bed-sediment samples with chlordane or dieldrin and water samples with lindane detected decreased significantly as the distance downstream from the Dallas-Fort Worth urban area increased.

Detections of malathion in water samples were positively correlated with urban and rangeland land-use classes. Pesticide use information shows that malathion currently is used in agricultural areas and probably was used during the sampling period, however malathion's low environmental persistence and relatively low use probably account for the negative correlation with agriculture. Use of malathion for mosquito and fire ant control probably accounts for its correlation with urban land use—particularly its use around water or wetland areas for mosquito control. Use as a livestock dip and spray and frequent use on ant mounds may explain the correlation with rangeland. The percentage of water samples with malathion detected decreased significantly as the distance downstream from the Dallas-Fort Worth urban area increased.

Interestingly, although 2,4–D was detected in 62 percent of all water samples and 47 percent of bed-sediment samples, no significant statistical correlation was detected with land-use class. The use of 2,4–D across all land-use classes likely explains the lack of correlation with any particular land-use class.

Detection of 2,4–D in water samples, however, was positively correlated with the Western Cross Timbers ILRU (table 6), and negatively correlated with the Texas Claypan and Bottomlands ILRUs. Extensive cropland and pasture existed in the Western Cross Timbers ILRU during the period of sampling and may be the source of 2,4–D detected in samples. Data collected by the city of Arlington, described earlier, showed 74 percent of samples had 2,4–D detected during 1980–90. Land-use information showed extensive cropland and pasture in the area upstream of these sites. The use of 2,4–D also is associated with turf-grass production and golf course operations. Detections of 2,4–D in samples likely are related to all of these land-use activities.

The distance from the mouth of the Trinity River to each of five mainstem U.S. Geological Survey water-quality stations was measured, ranked, and correlated with percent detects of the nine previously mentioned pesticides in water and bed sediment to assess any spatial pattern or relation in number of detects and proximity to the Dallas-Fort Worth urban area. Distance in river miles on the mainstem Trinity River upstream from the mouth was used rather than distance from the urban area in order to avoid problems associated with the definition of the "urban area." The statistically significant correlations, as listed in table 6, indicate that detections of the respective pesticides decrease as distance from the stream mouth decreases.

This analysis is valuable as a overview of the study area but has some recognized limitations. Although Spearman's rho is a valid test even for the relatively small number (7) of sampling sites, and although there are some correlations significant at the 90-percent confidence level, more sampling sites, distributed throughout the study area, would provide a better understanding of these relations. The current information is biased somewhat towards mainstem urban sites. Additionally, samples collected at multiple sites along the mainstem are not known to be statistically independent. Detailed information on the streamflow, particularly time-of-travel information, will help to more fully understand and describe the system. The land-use information could be improved because no distinction between cropland and pasture is possible—although pesticide applications in these two land uses vary significantly.

APPRAISAL OF AVAILABLE PESTICIDE DATA

The effects of pesticides on water quality can be described in terms of their potential impact on man and the environment. Many pesticides are toxic to humans and residues in water or food supplies can constitute a threat to human health. Ecological relationships can be significantly affected by the presence of pesticides. Nontarget biological species may be eliminated or reduced by the presence of various pesticides in their immediate environment. Those species higher on the food chain but dependent on the lower species for food obviously could be affected—with results possibly extending throughout the food chain. Additionally, many pesticides—particularly the organochlorines, due to their environmental persistence—accumulate in tissue of various organisms. This accumulation occurs as organisms absorb pesticides through skin and gills, take in pesticide-containing water and sediment during feeding, and ingest organisms lower on the food chain, which also have been exposed to pesticides in the environment.

Pesticides applied in cropland, forests, or urban areas may enter surface or ground water by rainfall or irrigation runoff, with amounts depending on pesticide application rates, formulation, and application timing, timing of runoff in relation to application, and pesticide properties such as surface loss and leaching potential. Monitoring programs can provide information on ambient levels of pesticides in surface or ground water but must take all of these factors into account. The monitoring programs and studies discussed in this report have shown that during the entire period covered by this report, a variety of pesticides were found in surface water, bed sediment, and tissue samples taken at sites throughout the Trinity River Basin study area; however, at this time no comprehensive data-collection program exists to provide new information on ambient pesticide levels necessary for any assessment of water quality with regard to pesticides.

Review of ground-water-sample data has shown no detections of any pesticide analyzed, however, these samples were collected from only a few agricultural areas in the State and included only 19 wells sampled (29 constituents) within the study area. Wells sampled for arsenic showed no detections, but figure 31 shows little correspondence between sampling well locations and those areas where pesticide-use data indicate that arsenic acid was applied, particularly the recharge areas of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

The environmental persistence of organochlorine pesticides has been described by various authors and is well known. This group of pesticides, first detected in samples at mainstem sites in 1968, was detected in one or more types of sample media as recently as 1988. The percent detections for combined organochlorine pesticides for two time periods are given in table 7. This comparison is possible because the organochlorines are the only class of pesticide that has been sampled consistently during the time period covered by this report. The data in table 7 indicate a much higher percentage of detections in the earlier data (1970–81) than in the later data (1985–88). This decrease in the number of samples with pesticides detected corresponds to the decline in use of this type of pesticide over these time periods; however, these compounds still persist.

In data sets including samples from more than one medium, the percentage of detects increases from water to bed sediment and then to tissue, which is the expected distribution of detections of organochlorine pesticides. Because of low solubility in water, organochlorine detections in water usually indicate recent introduction or reintroduction of these pesticides into the water column. Bed sediment and tissue detections indicate the natural tendency of organochlorines to accumulate in the bed sediment and ultimately in biological tissues. The characteristics of low solubility in water and affinity for fat tissues contribute to the effectiveness of pesticides and also to their persistence in the environment.

Samples collected as recently as 1988 indicate the continued presence of these compounds. Current NAWQA sampling efforts conducted in Livingston Reservoir (Peter Van Metre, U.S. Geological Survey, written commun., 1993) indicated mean concentrations of DDT were 0.24 μg/kg, of DDE were 5.59 μg/kg, and of DDD were 1.15 μg/kg, in samples from cores taken from the lake bottom. Reservoirs appear to be acting as repositories for the organochlorine compounds.

Table 7. Comparison of percent detections of organochlorine pesticides for two time periods

[---, no data collected]

Early (1970–81)		Late (1985–88)	
Sampling agency	**Percent detected**	**Sampling agency**	**Percent detected**
Water Column			
U.S. Geological Survey	14.8	U.S. Geological Survey	1.9
University of Texas at Arlington	73.1	University of North Texas	6.3
Dallas Water Utilities	81.1	---	---
Bed Sediment			
U.S. Geological Survey	29.6	U.S. Geological Survey	4.7
University of Texas at Arlington	79.0	University of North Texas	8.9
Tissue			
---	---	Texas Parks and Wildlife Department	57.9
---	---	U.S. Fish and Wildlife Service	31.4

NAWQA's listing of highest priority pesticides for future sampling includes many of the organochlorine compounds discussed in this report. This sample data will allow an up-to-date assessment of the current status of these pesticides.

Organophosphate pesticides have been detected, although less frequently, in samples taken as recently as 1983. The insecticide diazinon is ubiquitous in the study area, primarily because of its use both in urban areas on lawns and gardens, and in agricultural activities. It was detected in 60 percent of samples collected over the period of this report, and continues to be widely used throughout the study area. Samples for analyses of the major organophosphate pesticides in use in the study area will be collected during routine as well as synoptic sampling. These data will allow a current assessment of the ambient status of these heavily used pesticides in the mainstem of the Trinity, as well as in streams tributary to the Trinity.

Of the chlorophenoxy pesticides, 2,4–D has been detected most frequently, primarily because of its application on all types of land-use categories. In addition to agricultural uses, 2,4–D is used for weed control in forest and rangeland management, road and waterway maintenance, and in urban areas for weed control. Despite this widespread use, few studies have been conducted on this pesticide, and little is known of its fate in the environment (R.J. Gilliom, U.S.Geological Survey, written commun., 1993). Laboratory analysis of 2,4–D has been difficult and expensive but new techniques have been developed. A sampling program for 2,4–D has been developed as part of the NAWQA program, and samples were collected during 1993. Such samples would provide data to fill the gap in information on the occurrence and distribution of 2,4–D and other heavily used pesticides in the study area and in the Nation (R.J. Gilliom, written commun., 1993).

An ongoing effort includes the assembly and interpretation of ancillary data, which includes current land use, general soil properties, hydrogeologic characteristics, and other basin or anthropogenic characteristics. The plan is to use these data sets to more fully interpret spatial and temporal changes observed in pesticide sample data. Analysis of correlations between pesticide detects or concentrations and anthropogenic variables is an important step towards establishing cause and effect relations, one of the major goals of the NAWQA project. The cause and effect relations established are an integral part of the conceptual model being developed for the study area. The conceptual model will, in turn, allow inferences to be made about unsampled regions in the study area. The ability to make these inferences can support the wide variety of management decisions about the study area—from the design of an optimum sampling network to land use and zoning issues. A major goal in this area is to develop estimates of pesticide (and other compound) loads in order to conceptualize a "mass balance" of the study area.

The Trinity River Basin NAWQA includes a very significant effort in terms of describing the current status of aquatic organisms in relation to pesticides. Tissue samples will be collected and analyzed to determine the locations, types, and levels of pesticides in the aquatic environment.

SUMMARY

The Trinity River Basin study area extends approximately 360 mi to the north-northwest from its mouth at the Gulf of Mexico. Average annual precipitation varies from greater than 52 in. near the mouth to less than 32 in. in the extreme northwest. The variation in precipitation, combined with variations in temperature and surficial geology, has resulted in variations in landform, soils, and vegetation from southeast to northwest.

Total population of the basin was 4.5 million in 1990. Human modifications to the landscape and hydrologic system have been extensive. The natural environment of the basin has been altered by the development of livestock operations, cultivation of large areas of the study area, development of urban areas, discharge of wastewater, construction of reservoirs, and energy resource development. During 1973–81, about 57 percent of the study area was pasture or cropland. An additional 10 percent was rangeland, and 5 percent was urban or built-up land. Forest land, wetlands, open water, or barren land made up the remaining 28 percent. Twenty-two large and about 1,000 small reservoirs have been constructed on streams in the basin and numerous diversions carry water within the basin and to and from adjacent basins.

A variety of crops are grown throughout the study area, and most are routinely treated with pesticides. Wheat accounted for the largest number of acres treated annually at 541,250. Cotton accounted for the second largest number with 519,870 acres treated during 1988–90. Agricultural activities are important in the study area and are likely to remain so. Reliance on pesticides by agriculture is likely to continue for the foreseeable future.

Pesticides are human-made compounds and presence in samples indicates introduction to the environment by human activities rather than from natural sources. Pesticide occurrence and distribution in the study area are determined largely by human activities, particularly agriculture, and by physical factors present in the study area such as climate, soil, and landform.

Five major classes of pesticides have been applied to crops in the study area. These include: organochlorines, organophosphates, chlorophenoxy and triazine, carbamates, and a miscellaneous class. The use of organochlorine pesticides has been discontinued due to persistence in the environment, and in general has been replaced by organophosphate pesticides. Organophosphates are much less persistent in the environment than organochlorines but are highly toxic to many aquatic organisms. The organophosphate pesticides dimethoate and methyl parathion are the most heavily used in the study area for agriculture. Although not among the 24 most-used pesticides, based on agricultural use, diazinon and malathion are notable because of their use in urban areas. Diazinon is persistent in the environment but thought to be unlikely to contaminate ground water.

Chlorophenoxy and triazine pesticides are intermediate in environmental persistence and are applied extensively throughout the study area. The herbicide 2,4–D is the most heavily applied pesticide of this type. It is applied throughout the year in agricultural areas on both row crops and turf, as well as in urban areas.

Carbamate pesticides are used extensively in the study area, with carbaryl, carbofuran, methomyl, and thiodicarb accounting for the majority of the agricultural applications. Although

not among the 24 most-used pesticides, molinate is important in the rice farming areas.

Miscellaneous pesticides applied in the study area include alachlor, arsenic acid, picloram, and glyphosate, among others. In particular, arsenic acid is notable in its application as a desiccant in cotton-growing areas during the winter harvest. Glyphosate has widespread application in agricultural and urban areas.

Little information was available on the total quantities of pesticides used in the study area during the early period of this report, however average agricultural-use estimates were available for the period 1988–90. A total of 105 pesticides were used in agricultural activities during 1988–90. Twenty-four pesticides accounted for 75 percent of the average agricultural use in the study area during this period. Within this list of 24 are 7 pesticides identified by State officials as those most likely to contaminate ground water.

Estimates of nonagricultural use of pesticides indicate that, for some pesticides like 2,4–D, diazinon, and malathion, total use in the study area is probably many times higher than agricultural-use estimates alone. A comparison of national and study-area use of 15 pesticides (selected by data availability) indicates that herbicide use generally is proportionally higher in the study area than in the Nation, and that insecticide use generally is proportionally lower in the study area than in the Nation. Cotton was identified as the crop treated by the largest number of pesticides, and sorghum was second with 24 pesticides applied.

Eight agencies collected pesticide samples during the period covered by this report. The data were collected for various purposes and most of the large data sets were collected during routine monitoring of water quality. Other data were collected as part of studies addressing very specific or limited areas within the study area. Samples were collected by all agencies at a total of 155 surface-water sites and 100 ground-water sites. The sampled media included water, bed sediment, and tissue, but the types of samples collected varied depending on the sampling agency. In general, information on detection levels as well as quality-control information were available from the various agencies.

Some 273 samples were collected as part of the city of Arlington’s data collection program. The herbicide 2,4–D was detected in 74 percent of those samples, but none of the concentrations in samples exceeded the USEPA MCL for drinking water.

Dallas Water Utilities collected pesticide samples during a storm in February 1977. These samples were collected at 17 sites; several pesticides were detected in 50 percent or more of samples. Diazinon was detected in 56 percent of samples, and 2,4–D was detected in 56 percent of samples.

Texas Parks and Wildlife Department collected samples from fish tissue, for analysis of organochlorine pesticides, from 15 sites in the Dallas-Fort Worth area. Chlordane concentrations in some of the samples exceeded the USFDA action level of 300 μg/kg.

The Texas Water Commission collected ground-water samples in the study area during 1990 for the major types of pesticides and none were detected. Samples from 100 wells in or near the study area were analyzed for arsenic and none was detected. Organochlorine and organophosphate samples have been collected beginning 1974 and ending in 1991. Concentrations of organochlorine pesticides in bed sediment decrease with increasing distance downstream from the Dallas-Fort Worth urban area.

Irwin (1988) indicated significant correlation between mosquito fish body burdens of various organochlorine pesticides and residential areas. U.S. Geological Survey pesticide sample data indicated a significant rank correlation between number of detects of chlordane and percent of contributing watershed classified as urban land use. Urban land use also was correlated with dieldrin in bed-sediment samples, and lindane, diazinon, and malathion, in water samples. Chlordane and dieldrin also were correlated significantly with distance downstream from the Dallas-Fort Worth urban area.

Samples from water, bed sediment, and fish tissue were collected at 12 sites, by Dickson and others (1989). Concentrations of organochlorine pesticides were detected in all sample media. Chlordane concentrations exceeded USEPA standards for water and for tissues at three sites. The detection of organochlorine pesticides in tissue at stations where no pesticides were detected in either water or bed sediments might be explained by fish migration.

Qasim and others (1980) found chlordane in 46 percent of bed-sediment samples but none in water samples. Pesticide concentrations were found to be highest in samples collected from water obtained from central reaches of the river, which are associated with the major urban areas in the study area.

Review of available data indicated that pesticides were detected in samples taken from water, bed sediment, and tissue from sites located throughout the study area. In general, the detections of many of these pesticides decreased downstream from the Dallas-Fort Worth area, but a significant agricultural contribution of pesticides is present, as evidenced by detections of 2,4–D in samples collected from agricultural areas in the study area. The use of many of the pesticides sampled during the earliest periods covered by this report has been discontinued, but others continue to be used, as more current data indicate. Newer types of pesticides are being used, with little knowledge of their fate in the environment, however no current comprehensive basinwide sampling network for pesticides exists to provide information on ambient levels of these pesticides. Current NAWQA sampling efforts are providing some of the up-to-date information to be used for an accurate and timely assessment of the occurrence and distribution of pesticides in the Trinity River.

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Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency

[---, not available; Do., ditto; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; µg/L, micrograms per liter]

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
			City of Arlington, Texas				
1982, 1984, 1986–88	Aldrin	---	5	24	100	Routine monitoring	Water column (unfiltered)
1981–82, 1984, 1987–90	BHC-alpha	---	6	51	100	Do.	Do.
1989–90	CDAA	---	6	11	100	Do.	Do.
1980, 1983–90	2,4–D	0.025	12	273	74	Do.	Do.
1984, 1990	DDT-p,p	---	4	9	100	Do.	Do.
1984, 1987–89	Diazinon	---	5	22	100	Do.	Do.
1984	Dieldrin	---	3	6	100	Do.	Do.
1989	Dinocap	---	5	9	100	Do.	Do.
1984–88, 1990	Endosulfan Sulfate	---	5	14	100	Do.	Do.
1980–87, 1989–90	Endrin	0.2, 2.0	12	172	2	Do.	Do.
1984, 1987–88	Heptachlor	---	5	24	100	Do.	Do.
1981–82, 1984, 1987–90	Heptachlor Epoxide	0.16, 0.3	5	14	71	Do.	Do.
1980–87, 1989–90	Lindane (gamma-BHC)	0.2, 1.0	13	171	9	Do.	Do.
1980–91	Methoxychlor	100	13	184	7	Do.	Do.
1986–89	Methyl Parathion	---	5	19	100	Do.	Do.
1986, 1988–90	Nonachlor, trans-	---	5	11	100	Do.	Do.
1980, 1983–90	2,4,5–TP	5.0	13	265	59	Do.	Do.
1980–87, 1989–90	Toxaphene	5.0	13	164	9	Do.	Do.
			Dallas Water Utilities				
1976–77	Aldrin	---	17	113	26	Urban storm runoff study	Storm runoff (unfiltered)
Do.	BHC-alpha	---	17	113	92	Do.	Do.
Do.	2,4–D	---	17	113	56	Do.	Do.
Do.	DDT	---	17	113	50	Do.	Do.
Do.	Diazinon	---	17	113	56	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
				Dallas Water Utilities—Continued			
1976–77	Dieldrin	---	17	113	87	Urban storm runoff study	Storm runoff (unfiltered)
Do.	Endrin	---	17	113	4	Do.	Do.
Do.	Heptachlor	---	17	113	55	Do.	Do.
Do.	Heptachlor Epoxide	---	17	113	17	Do.	Do.
Do.	Lindane	---	17	113	90	Do.	Do.
Do.	Methoxychlor	---	17	113	8	Do.	Do.
Do.	Methyl Parathion	---	17	113	2	Do.	Do.
Do.	Phosdrin	---	17	113	2	Do.	Do.
Do.	Ponnel	---	17	113	2	Do.	Do.
Do.	2,4,5-T	---	17	113	13	Do.	Do.
Do.	2,4,5-TP	---	17	113	19	Do.	Do.
Do.	Thimet	---	17	113	1	Do.	Do.
Do.	Toxaphene	---	17	113	0	Do.	Do.
				Texas Parks and Wildlife Department			
1987–88	Chlordane	10	15	41	76	Study of water quality and fish assemblages	Fish tissue (fillets of various species)
Do.	DDT	5	15	41	34	Do.	Do.
Do.	DDE	5	15	41	76	Do.	Do.
Do.	Dieldrin	6	15	41	46	Do.	Do.
				Texas Water Commission			
1974–90	Aldrin	0.2, 0.5, 1.0	41	185	1	Routine monitoring	Bed sediments
1974–90	Chlordane	[1]2.0, 3.0, 10.0, 20.0	41	183	25	Do.	Do.
1978–91	2,4–D	[1]2.04, 2.86, 10.04, 50.0	31	88	6	Do.	Do.
Do.	DDT	[1]0.2, 2.0, 3.0, 5.0, 8.0	41	186	6	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
			Texas Water Commission—Continued				
1978–91	DDE	[1]0.2, 1.0, 1.5, 2.0, 5.0, 6.5	41	186	14	Routine monitoring	Bed sediment
Do.	DDD	[1]0.2, 1.0, 3.0, 5.0, 8.0	41	186	2	Do.	Do.
Do.	Diazinon	[1]0.53, 0.68, 5.0	41	183	7	Do.	Do.
Do.	Dieldrin	[1]0.02, 0.2, 1.0, 3.0	41	187	9	Do.	Do.
Do.	Endrin	[1]0.2, 1.0, 3.0, 5.0, 20.0	41	185	0	Do.	Do.
1989–91	Endosulfan Sulfate	[1]0.04, 0.07, 0.08, 0.11, 1.1	12	15	0	Do.	Do.
1974–91	Heptachlor	[1]0.03, 0.08, 0.11, 0.2, 0.5, 1.0	41	185	4	Do.	Do.
1974–91	Heptachlor Epoxide	[1]0.2, 0.25, 0.5, 1.0, 40.0	41	185	1	Do.	Do.
1974–91	Lindane	[1]0.2, 1.0, 2.0, 40.0	41	183	9	Do.	Do.
1980–91	Malathion	[1]1.0, 2.86, 5.0, 15.58, 113.0	34	130	0	Do.	Do.
1980–91	Methoxychlor	[1]1.0, 2.0, 10.0, 20.0	41	185	0	Do.	Do.
1974–91	Parathion	[1]0.13, 0.23, 0.81, 1.0, 3.0	41	185	1	Do.	Do.
1974–91	2,4,5–T	[1]0.61, 0.76, 10.0	31	88	5	Do.	Do.
1974–91	Toxaphene	[1]2.0, 5.0, 50.0	41	184	0	Do.	Do.
1990	Arsenic	10, 25	121	121	0	Do.	Ground water (unfiltered)

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
Texas Water Commission—Continued							
1990	Alachlor	0.1	3	3	0	Routine monitoring	Ground water (unfiltered)
Do.	BHC-alpha	0.03, 11.0	18	18	0	Do.	Do.
Do.	BHC-beta	0.03, 11.0	18	18	0	Do.	Do.
Do.	BHC-delta	0.03	15	15	0	Do.	Do.
Do.	Chlordane-cis	0.02	3	3	0	Do.	Do.
Do.	Chlordane-trans	0.02	3	3	0	Do.	Do.
Do.	2,4–D	20.0	5	5	0	Do.	Do.
Do.	DDT	0.15, 0.3	5	5	0	Do.	Do.
Do.	DDE	0.1, 0.2	5	5	0	Do.	Do.
Do.	DDD	0.15, 0.3	5	5	0	Do.	Do.
Do.	Diazinon	0.3	2	2	0	Do.	Do.
Do.	Dicamba	1.0, 5.0	5	5	0	Do.	Do.
Do.	Dieldrin	0.1	18	18	0	Do.	Do.
Do.	Endosulfan	0.2	5	5	0	Do.	Do.
Do.	Endosulfan II	0.2	3	3	0	Do.	Do.
Do.	Endosulfan Sulfate	0.2, 21.0	18	18	0	Do.	Do.
Do.	Endrin	0.2, 21.0	17	17	0	Do.	Do.
Do.	Heptachlor	0.02, 11.0	17	17	0	Do.	Do.
Do.	Heptachlor Epoxide	0.06, 21.0	17	17	0	Do.	Do.
Do.	Lindane (BHC-gamma)	0.03, 11.0	18	18	0	Do.	Do.
Do.	Malathion	0.4	5	5	0	Do.	Do.
Do.	Methoxychlor	0.5	5	5	0	Do.	Do.
Do.	Methyl Parathion	0.25	5	5	0	Do.	Do.
Do.	Parathion	0.25	6	6	0	Do.	Do.
Do.	Picloram	3.0	5	5	0	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
Texas Water Commission—Continued							
1990	2,4,5–T	5.0	5	5	0	Routine monitoring	Ground water (unfiltered)
Do.	2,4,5–TP	5.0	5	5	0	Do.	Do.
Do.	Toxaphene	5.0	5	5	0	Do.	Do.
Do.	Trifluralin	0.006	5	5	0	Do.	Do.
1983–89	DDT sum analogs	0.01 µg/g	12	18	28	Do.	Tissue
1983–89	Dieldrin	0.006 µg/g	12	18	89	Do.	Tissue
1974–76, 1982, 1984–86, 1990–91	2,4–D	0.01, 10.0, 20.0, 50.0	20	62	35	Do.	Water column (unfiltered)
1974–76, 1982, 1984–86, 1990–91	2,4,5–TP	0.01, 10.0, 20.0	17	58	33	Do.	Do.
U.S. Fish and Wildlife Service							
1985	BHC-beta	10	27	64	2	Study of contaminants in aquatic life	Tissues of fish and other aquatic wildlife (whole bodies of various species)
Do.	Chlordane (total)	10	27	64	92	Do.	Do.
Do.	Chlordane, cis- (alpha)-	10	27	64	66	Do.	Do.
Do.	DDT	10	27	64	0	Do.	Do.
Do.	DDD	10	27	64	5	Do.	Do.
Do.	DDE	10	27	64	42	Do.	Do.
Do.	Dieldrin	10	27	64	77	Do.	Do.
Do.	Heptachlor Epoxide	10	27	64	8	Do.	Do.
Do.	Lindane (BHC-gamma)	10	27	64	11	Do.	Do.
Do.	Mirex	10	27	64	5	Do.	Do.
Do.	Nonachlor, trans-	10	27	64	34	Do.	Do.
Do.	Nonachlor, cis-	10	27	64	34	Do.	Do.
Do.	Oxychlordane	10	27	64	33	Do.	Do.
Do.	Total non-DDT organochlorines	100	27	64	53	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
			U.S. Geological Survey				
1970–81	Aldrin	0.1	6	132	9	Routine water-quality monitoring	Bed sediments
Do.	Chlordane	0.1	6	135	64	Do.	Do.
Do.	2,4–D	0.1	6	18	6	Do.	Do.
Do.	DDT	0.1	6	135	22	Do.	Do.
Do.	DDD	0.1	6	135	54	Do.	Do.
Do.	DDE	0.1	6	135	49	Do.	Do.
Do.	Dieldrin	0.1	6	135	72	Do.	Do.
Do.	Diazinon	0.1	6	12	0	Do.	Do.
Do.	Endosulfan	0.1	6	8	0	Do.	Do.
Do.	Endrin	0.1	6	135	8	Do.	Do.
Do.	Ethion	0.1	6	6	0	Do.	Do.
Do.	Heptachlor	0.1	6	135	12	Do.	Do.
Do.	Heptachlor Epoxide	0.1	6	135	16	Do.	Do.
Do.	Lindane	0.1	6	135	16	Do.	Do.
Do.	Malathion	0.1	6	20	0	Do.	Do.
Do.	Methoxychlor	0.1	6	21	0	Do.	Do.
Do.	Methyl Parathion	0.1	6	22	0	Do.	Do.
Do.	Mirex	0.1	6	8	0	Do.	Do.
Do.	Parathion	0.1	6	22	0	Do.	Do.
Do.	2,4,5–T	0.1	6	14	0	Do.	Do.
Do.	2,4,5–TP	0.1	6	14	0	Do.	Do.
Do.	Toxaphene	10	6	97	5	Do.	Do.
1985–88	Aldrin	0.1	1	10	0	Do.	Do.
Do.	Chlordane	1.0	1	11	9	Do.	Do.
Do.	2,4–D	0.1	1	10	1	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
			U.S. Geological Survey—Continued				
1985–88	DDT	0.1	1	11	9	Routine water-quality monitoring	Bed sediments
Do.	DDD	0.1	1	11	9	Do.	Do.
Do.	DDE	0.1	1	11	18	Do.	Do.
Do.	Diazinon	0.1	1	11	0	Do.	Do.
Do.	Dieldrin	0.1	1	11	9	Do.	Do.
Do.	Endosulfan	0.1	1	10	0	Do.	Do.
Do.	Endrin	0.1	1	11	0	Do.	Do.
Do.	Ethion	0.1	1	11	0	Do.	Do.
Do.	Heptachlor	0.1	1	11	0	Do.	Do.
Do.	Heptachlor Epoxide	0.1	1	11	0	Do.	Do.
Do.	Lindane	0.1	1	11	0	Do.	Do.
Do.	Malathion	0.1	1	11	0	Do.	Do.
Do.	Methoxychlor	0.1	1	10	0	Do.	Do.
Do.	Methyl Parathion	0.1	1	11	0	Do.	Do.
Do.	Mirex	0.1	1	10	10	Do.	Do.
Do.	Parathion	0.1	1	11	0	Do.	Do.
Do.	2,4,5–T	0.1	1	10	0	Do.	Do.
Do.	2,4,5–TP	0.1	1	10	0	Do.	Do.
Do.	Toxaphene	10	1	11	0	Do.	Do.
1968–81	Aldrin	0.1	6	186	3	Do.	Do.
Do.	Chlordane	0.1	6	179	30	Do.	Do.
Do.	2,4–D	0.01	6	181	73	Do.	Do.
Do.	DDT	0.01	6	197	24	Do.	Do.
Do.	DDD	0.01	6	197	16	Do.	Do.
Do.	DDE	0.01	6	197	8	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
			U.S. Geological Survey—Continued				
1970–81	Diazinon	0.01	6	167	75	Routine water-quality monitoring	Water column (unfiltered)
1968–81	Dieldrin	0.01	6	197	45	Do.	Do.
1977–81	Endosulfan	0.01	6	51	0	Do.	Do.
1968–81	Endrin	0.01	6	186	0	Do.	Do.
1975–81	Ethion	0.01	6	100	1	Do.	Do.
1968–81	Heptachlor	0.01	6	186	1	Do.	Do.
Do.	Heptachlor Epoxide	0.01	6	186	4	Do.	Do.
Do.	Lindane	0.01	6	196	33	Do.	Do.
1970–81	Malathion	0.01	6	169	32	Do.	Do.
1968–81	Methoxychlor	0.01	6	40	3	Do.	Do.
1970–81	Methyl Parathion	0.01	6	170	1	Do.	Do.
1968–81	Mirex	0.01	6	41	0	Do.	Do.
1970–81	Parathion	0.01	6	169	2	Do.	Do.
1968–81	2,4,5–T	0.01	6	181	74	Do.	Do.
Do.	2,4,5–TP	0.01	6	181	11	Do.	Do.
Do.	Toxaphene	1.0	6	130	1	Do.	Do.
1985–88	Aldrin	0.01	1	11	9	Do.	Do.
Do.	Chlordane	0.1	1	11	0	Do.	Do.
Do.	2,4–D	0.01	1	8	0	Do.	Do.
Do.	DDT	0.01	1	11	9	Do.	Do.
Do.	DDD	0.01	1	11	0	Do.	Do.
Do.	DDE	0.01	1	11	0	Do.	Do.
Do.	Diazinon	0.01	1	10	75	Do.	Do.
Do.	Dieldrin	0.01	1	11	0	Do.	Do.
Do.	Endosulfan	0.01	1	11	9	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (μg/L) or (μg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
				U.S. Geological Survey—Continued			
1985–88	Endrin	0.01	1	11	0	Routine water-quality monitoring	Water column (unfiltered)
Do.	Ethion	0.01	1	10	0	Do.	Do.
Do.	Heptachlor	0.01	1	11	0	Do.	Do.
Do.	Heptachlor Epoxide	0.01	1	11	0	Do.	Do.
Do.	Lindane	0.01	1	11	0	Do.	Do.
Do.	Malathion	0.01	1	10	11	Do.	Do.
Do.	Methoxychlor	0.01	1	11	0	Do.	Do.
Do.	Methyl Parathion	0.01	1	10	20	Do.	Do.
Do.	Mirex	0.01	1	11	0	Do.	Do.
Do.	Parathion	0.01	1	9	10	Do.	Do.
Do.	2,4,5–T	0.01	1	9	0	Do.	Do.
Do.	2,4,5–TP	0.01	1	9	0	Do.	Do.
Do.	Toxaphene	1.0	1	11	0	Do.	Do.
				University of North Texas and University of Texas at Dallas			
1987–88	Aldrin	0.004, 0.016	12	72	31	Water-quality and ecological survey	Bed sediments
Do.	Chlordane	0.014, 0.056	12	72	11	Do.	Do.
Do.	DDT	0.012, 0.048	12	72	7	Do.	Do.
Do.	DDD	0.011, 0.044	12	72	3	Do.	Do.
Do.	DDE	0.004, 0.016	12	72	7	Do.	Do.
Do.	Dieldrin	0.002, 0.008	12	72	0	Do.	Do.
Do.	Endosulfan I	0.014, 0.056, 0.066	12	72	0	Do.	Do.
Do.	Endosulfan II	0.004, 0.016	12	72	1	Do.	Do.
Do.	Endrin	0.006, 0.024	12	72	7	Do.	Do.
Do.	Endrin Aldehyde	0.023, 0.092	12	72	10	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (μg/L) or (μg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
			University of North Texas and University of Texas at Dallas—Continued				
1987–88	Heptachlor	0.003, 0.012	12	72	15	Water-quality and ecological survey	Bed sediments
Do.	Heptachlor Epoxide	0.083, 0.332	12	72	10	Do.	Do.
Do.	Lindane (BHC-gamma)	0.004, 0.006, 0.024, 0.036	12	72	24	Do.	Do.
Do.	Toxaphene	0.240, 0.300, 0.960	12	72	0	Do.	Do.
Do.	Aldrin	0.02	12	39	10	Do.	Fish tissue (whole bodies of sunfish)
Do.	Chlordane	---	12	39	21	Do.	Do.
Do.	DDT	0.02	12	39	3	Do.	Do.
Do.	DDE	0.02	12	39	31	Do.	Do.
Do.	DDD	0.48	12	39	28	Do.	Do.
Do.	Dieldrin	0.2	12	39	10	Do.	Do.
Do.	Endrin	0.07	12	39	0	Do.	Do.
Do.	Endrin Aldehyde	0.3	12	39	8	Do.	Do.
Do.	Heptachlor	0.02	12	39	18	Do.	Do.
Do.	Heptachlor Epoxide	0.02	12	39	18	Do.	Do.
Do.	Lindane	0.06	12	39	5	Do.	Do.
Do.	Aldrin	0.011	12	71	4	Do.	Water column (unfiltered)
Do.	BHC-alpha	0.009	12	72	14	Do.	Do.
Do.	BHC-beta	0.004	12	72	1	Do.	Do.
Do.	BHC-delta	0.003	12	72	13	Do.	Do.
Do.	Chlordane	0.014	12	72	10	Do.	Do.
Do.	DDT	0.012	12	72	5	Do.	Do.
Do.	DDD	0.011	12	72	5	Do.	Do.
Do.	DDE	0.004	12	72	1	Do.	Do.

Footnote at end of table.

Table 4. Frequency of sampling and detections, methods, and purpose(s) of collection by sampling agency—Continued

Sampling period	Pesticide name	Detection limit (µg/L) or (µg/kg) or as indicated	Number of sites	Number of samples	Percent of samples with concentrations above detection limit	General sample-collection purposes	Sample media
University of North Texas and University of Texas at Dallas—Continued							
1987–88	Diazinon	---	12	48	8	Water-quality and ecological survey	Water column (unfiltered)
Do.	Dieldrin	0.002	12	72	4	Do.	Do.
Do.	Endosulfan I	0.014	12	72	0	Do.	Do.
Do.	Endosulfan II	0.004	12	72	0	Do.	Do.
Do.	Endosulfan Sulfate	0.066	12	72	3	Do.	Do.
Do.	Endrin	0.006	12	72	4	Do.	Do.
Do.	Endrin Aldehyde	0.023	12	72	7	Do.	Do.
Do.	Heptachlor	0.003	12	72	3	Do.	Do.
Do.	Heptachlor Epoxide	0.083	12	72	4	Do.	Do.
Do.	Lindane (BHC-gamma)	0.006	12	72	29	Do.	Do.
Do.	Toxaphene	0.240	12	72	0	Do.	Do.
University of Texas at Arlington (for U.S. Corps of Engineers)							
1977	Chlordane	0.3	13	13	46	Study of water and bed-sediment quality and contaminant mobility during dredging	Bed sediments
Do.	DDT	0.5	13	13	85	Do.	Do.
Do.	Dieldrin	0.3	13	13	85	Do.	Do.
Do.	Endrin	0.3	13	13	92	Do.	Do.
Do.	Heptachlor	0.3	13	5	100	Do.	Do.
Do.	Lindane	0.2	13	5	80	Do.	Do.
Do.	Chlordane	0.3	13	13	0	Do.	Water column (unfiltered)
Do.	DDT	0.5	13	13	77	Do.	Do.
Do.	Dieldrin	0.3	13	13	92	Do.	Do.
Do.	Endrin	0.3	13	13	85	Do.	Do.
Do.	Heptachlor	0.3	13	13	85	Do.	Do.
Do.	Lindane	0.2	13	13	100	Do.	Do.

[1] This is a representative group of the multiple detection limits given for this compound.